Research to Inform Community-Led Action to Reduce Tsunami Impact, Wharekauri-Rekohu-Chatham Islands, Aotearoa-New Zealand

A Thesis submitted in fulfilment of the requirements for the Degree

of Master of Science in Disaster Risk and Resilience

by

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FRONTISPIECE

Remains of a European house at Tupuangi (Wharekauri-Rekohu-Chatham Islands, New Zealand) that was inundated and destroyed by the 1868 Arica tsunami. This location, Tupuangi, was once a flourishing Māori settlement that was abandoned after the event.

ABSTRACT

During disasters, exposed and vulnerable communities bear the brunt of impacts and are first to respond. People of these communities obtain local and/or indigenous knowledge and understanding of locally-specific challenges and opportunities, which no external expert could derive alone. Participatory, community-based disaster risk reduction involves participation of people who may be directly impacted by disasters, to encourage sharing of valuable local knowledge and to empower both communities and local authorities to reduce vulnerabilities and strengthen capacities. This participatory process is carried out for, with, and by the community to form DRR initiatives that are well-informed and invested in by all involved, and thus are more effective.

Tsunami are powerful, natural phenomena which can cause considerable impacts on exposed and vulnerable communities. Wharekauri-Rekohu-Chatham Islands is an archipelago in the Pacific Ocean approximately 800 km east of Aotearoa-New Zealand (A-NZ) and is exposed on all sides to tsunami generated from local, regional and distant sources. Past tsunami events on Chatham Islands have been destructive, causing loss of property, infrastructure and, in one case, fatality. Previous tsunami research on the Chatham Islands has focused on hazard assessment. While this provides a major contribution towards understanding tsunami hazard for the Chatham Islands, the assessments are incomplete or limited by uncertainties in model input parameters. More research is required to better understand tsunami hazard for the Chatham Islands to inform effective reduction, readiness, response and recovery initiatives. Current disaster risk reduction (DRR) initiatives on the Chatham Islands are also limited by lack of understanding of societal assets exposed, their vulnerability (as well as capacity), and potential impacts.

Although A-NZ has access to pre-written records of past, high-impact, tsunami impacts within Tangata Whenua knowledge systems, Tangata Whenua knowledge of past events on the Chatham Islands has not been explored previously. High-impact tsunami events can cause considerable damage to infrastructure networks, resulting in significant disruption of essential services (water, communications, electricity, transportation corridors), which are critical during disasters to enable effective response and recovery activities. During a high-impact tsunami event which affects locations across A-NZ, the Chatham Islands may be isolated from external assistance for an extended period of time. In this situation, the performance of essential services and on-island capacity to restore services may have considerable influence on response and recovery.

The overall aim of the thesis is to inform and to engender community-led and community-based actions to reduce future tsunami impact, through participation of the Chatham Islands community throughout the research, to produce useful and usable outcomes. This involves addressing the following objectives:

a) Improve the current understanding of tsunami hazard for the Chatham Islands by investigating past event impacts and inundation extents in documented accounts and Tangata Whenua knowledge/oral history.
b) Assess potential impacts on societal assets, in particular infrastructure components, to evaluate resultant levels of essential services based on expert judgment from local infrastructure personnel to form a credible high-impact tsunami scenario.
c) To share this information with the Chatham Islands community to co-develop actions to reduce future tsunami impact through the use of participatory tools facilitated during workshops.

To achieve these objectives, an impact assessment was conducted, following the Risk Management Framework (AS/NZS ISO 31000:2009) to identify risk (improving understanding of tsunami hazard and identify exposed societal assets), analyse risk (through combining hazard and exposure metrics to evaluate vulnerability and subsequent impacts) and evaluate risk (through the community identifying underlying vulnerabilities and capacities) to inform co-developed risk treatment options (derived in the workshops).

The combination of documented accounts and Tangata Whenua knowledge brought to light a wealth of information on past tsunami impacts and inundation extents which is not included in detailed national tsunami databases. The credible, high-impact scenario suggests that a significant amount of infrastructure is exposed and vulnerable to tsunami inundation, and that problematic impacts occur in the scenario which exceeds the capacity on-island resources to restore functionality of some assets and services. The scenario results are presented, and as discussed, are uncertain but provided a useful tool for the participatory workshops. The participatory workshops revealed that Chatham Islanders have great capacity to survive on their own if disconnected from services from A-NZ during and following a high-impact tsunami event. This is partly due to a tightly-connected community, as well as a community of people who are highly adaptive and resourceful (due to experience of living in isolation). However, workshop participants also identified key vulnerabilities in dependence on lifeline infrastructure and essential services during warnings, response and recovery. Although there was a high degree of confidence that the community could cope, the workshops highlighted some issues that had not yet been considered but would be crucial during a time of high stress. With local planning and action these issues could be addressed and help to reduce tsunami impacts on the Chatham Island community.

In summary, this thesis:

- Presents the first contribution to understanding tsunami risk to Chatham Island society. This information will better inform future impact reduction, readiness, response and recovery initiatives.
- Provides a demonstrable application of how community participation can be successfully incorporated into the disaster risk assessment process, especially in the New Zealand context. This work can be used to guide similar future studies to develop useful and usable outcomes for, with and by communities.
- Provides a credible, high-impact tsunami scenario that includes resultant levels of essential services, which could be used to run future exercises with Civil Defence and Emergency Management (CDEM), infrastructure providers and the community,
- Provides a list of community-derived recommendations for action to reduce future tsunami impact. These actions could be taken by individuals, households, businesses and agencies responsible for emergency management in the Chatham Islands.

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LIST OF ACRONYMS

A-NZ	Aotearoa-New Zealand
CBDRR	Community-based DRR
CIC	Chatham Islands Council (a unitary authority)
CCC	Christchurch City Council
CRI	Crown-owned Research Institute
DEM	Digital Elevation Model
DOC	Department of Conservation
DRR	Disaster Risk Reduction
DS	Damage State/s
ECan	Environment Canterbury Regional Council
EOC	Emergency Operation Center
EQC	Earthquake Commission
GEJ	Great East Japan Tsunami of 2011
GIS	Geographic Information System
GNS Science	Geological and Nuclear Science
GFDRR	Global Facility for Disaster Reduction and Recovery
GPS	Global Positioning System
HVCA	Hazard Vulnerability Capacity Analysis
HMT	Hokotehi Moriori Trust
NIWA	National Institute for Water and Atmospheric Research
IFRC	International Federation of Red Cross and Red Crescent Societies

IK	Indigenous Knowledge
LoS	Levels of Service
MBIE	Ministry of Business and Innovation
MCDEM	Ministry of Civil Defence and Emergency Management
MHWS	Mean high water spring
MSA	Maritime Safety Authority
MSL	Mean Sea Level
NMoWIT	Ngāti Mutunga O Wharekauri Iwi Trust
PLA	Participatory Learning and Action
RMF	Risk Management Framework
R-R-PI	Rangiauria-Rangihaute-Pitt Island
TWK	Tangata Whenua knowledge
UC	University of Canterbury
UNISDR	United Nations Office for Disaster Risk Reduction
W-R-CI	Wharekauri-Rekohu-Chatham Islands

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1 INTRODUCTION

1.1 CONTEXT OF STUDY

Tsunami are powerful natural phenomena which can cause considerable impacts on exposed and vulnerable communities. Tsunami, like other hazards, occur in a range of magnitudes; smaller tsunami that may not inundate land occur more frequently than tsunami that inundate land. High-impact (and infrequent) tsunami, such as the devastating events of the 2004 Boxing Day Indonesian tsunami, the 2011 Great East Japan tsunami and the 2015 Chile tsunami have the potential to cause massive losses of life, property and infrastructure (Power, 2013; Fraser et al., 2013; Tomita et al., 2006).

New Zealand has a long history of tsunami, a detailed record of historical tsunami impacts and has access to pre-written knowledge of tsunami in oral histories (De Lange & Healy, 1986; McFadgen, 2007; King, Goff & Skipper, 2007; King & Goff, 2010; GNS Science, 2014; King, 2015; New Zealand Palaeotsunami Database, 2017; King et al., 2018). The entire New Zealand coastline is exposed to tsunami from local, regional and distant sources (Power & Gale, 2011). The Hikurangi Subduction Zone, a regional tsunami source, is A-NZ's dominant tsunami threat. However, distant sourced tsunami generated from earthquakes along the Peruvian Subduction Zone (South America), are the most frequent. Earthquakes (thought to be greater than Mw 8.5) generated on the Peruvian Subduction Zone capable of generating tsunami that could impact A-NZ shores occur on average, every 50 years (Power, 2013a). Historical tsunami from this source have produced wave heights of greater than 8 m at locations in New Zealand (Power, 2013a). Wharekauri-Rekohu-Chatham Islands is the most exposed location in A-NZ to this source; it will be the first impacted locality during these events and has dominantly been affected by distant source tsunami in the past (Berryman, 2005; Power, 2013a).

The Chatham Islands are located 850 km east of Christchurch, New Zealand, and include two inhabited islands, Chatham Island (Wharekauri/Rekohu) and Pitt Island (Rangiauria/Rangihaute) (Figure 1.6). These have a combined population of approximately 600 (Statistics New Zealand, 2013). The Chatham Islands are vulnerable to tsunami impact due to their location, low elevation and isolation.

Previous tsunami research on the Chatham Islands has focused on hazard assessment. Thus, current disaster risk reduction (DRR) initiatives are limited by a lack of the understanding of exposure, vulnerability, potential impacts and community capacities that are needed to inform more effective preparedness, response and recovery plans. Therefore, further research is required. Of interest to Chatham Islands Council, Environment Canterbury Regional Council (ECan), Iwi and infrastructure companies is the extent of past tsunami inundations, potential tsunami impacts on infrastructure and potential loss of services, community awareness of tsunami hazard, and response and recovery needs. For this information to be useful to and usable by the community, the research information needs to be co-developed and validated with the community who hold a depth of local knowledge. This research presents a unique opportunity; I grew up on the Chatham Islands, most of my whānau still live there and I am Tangata Whenua (a descendant of the indigenous peoples of the Chatham Islands). My pre-existing relationships Chatham Islanders, the Island and my local knowledge provided a head start in regards to the participatory process involved in this study.

1.2 Research Aims and Objectives

The aim of this thesis is to engender community-led action to reduce tsunami impact on the Chatham Islands. This will be achieved by collating and co-developing information with the community to co-develop useful and usable recommendations for action that can be carried out by players such as the Ministry of Civil Defence and Emergency Management (MCDEM) as well as local and regional CDEM groups, local businesses, community groups, households and individuals. This involves combining scientific and local knowledge during all phases of the project and dialogue with all stakeholders to engender bottom-up and top-down initiatives intended to reduce future tsunami impact. Therefore, this thesis is intended to be accessible to and understandable by emergency management staff and the Chatham Island community to help guide future decisions and resilience planning. The research objectives have been organised into sub-sections as follows;

Characterisation of Tsunami Hazard

1. Review literature of Māori indigenous knowledge of tsunami, Māori research methodologies and terminology.
2. Explore documented accounts and Tangata Whenua (people of the land, including Māori and Moriori) knowledge and/or local knowledge (possessed by pākehā - European or other heritage) of past tsunami inundation and impacts on the Chatham Islands.

3. Develop a credible tsunami inundation scenario.

Tsunami Impact Assessment and Impact Scenario Development

4. Review literature and case studies of tsunami impact assessments for infrastructure and loss of services including available tsunami vulnerability models to inform methods for this study.
5. Gather an understanding of infrastructure systems on the Chatham Islands, their interdependencies, vulnerabilities and capacity to function following tsunami impact.
6. Improve the exposure inventory generated by Thomas (2017), collect GPS points, asset attributes, hotspot and pinchpoint locations and criticality of the networks to assess vulnerability.
7. Generate a credible tsunami impact scenario that overlays hazard, exposure and vulnerability information to identify areas of high exposure and vulnerability and to inform practical and effective disaster impact reduction initiatives.

Participatory Community Workshops

8. Share the methods and results of the investigation of historical tsunami impacts and inundation extents, as well as the inundation and impact (LoS) scenario development, with stakeholders and community representatives.
9. Collect and incorporate feedback from the stakeholders and community representatives on the past tsunami investigations and impact assessment.
10. Use participatory tools to:
    a. evaluate the consequences of the impact scenario on the community,
    b. explore community vulnerability and the capacity to respond to tsunami impacts presented, and
    c. co-develop a list of actions that could be taken by individuals, households and/or agencies to reduce tsunami impact both now, and during a tsunami warning.

This Chapter introduces the thesis. Firstly, disaster risk reduction, and its global and local application are described, before community participation in DRR introduced. The Risk Management Framework (AS/NZS, 2009), which is used as the conceptual framework of this thesis, is then outlined before introducing the Chatham Islands, outlining the research methodology and thesis structure.

1.3 Disaster Risk Reduction (DRR)

1.3.1 What is DRR?

Pre-millennium efforts to reduce the impacts of disasters focused on improving emergency response systems, partly founded on the misunderstanding that disasters were natural events (PreventionWeb, 2014). Disasters are not natural events, they can be naturally-triggered, but it is the exposure and vulnerability of societal assets that determines how severe impacts are and this influences the scale of the disaster.

Disasters can occur when a natural hazard (natural phenomenon such as an earthquake, landslide, tsunami, volcanic eruption which has an associated likelihood and intensity) interacts with societal conditions of exposure, vulnerability and capacity triggering serious disruption of a community and causing: human, material, economic and/or environmental losses and impacts. During a disaster, the losses and impacts are beyond the capacity of the society to cope and restore functionality by using its own resources (GFDRR, 2014; UNISDR, 2017).

Exposure refers to "the situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas," (UNISDR, 2017).

Vulnerability can be defined as the "conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards," (UNISDR, 2017). For example, these conditions may include structural integrity of an asset, income, insurance, age, gender, as well as dependence on resources or services. Vulnerability can be reduced by capacities.

Capacities are the set of strengths, attributes and resources an individual, household or community may have access to, that allow them to resist, cope, and recover from a disaster (Wisner et al., 2004; UNISDR, 2017). These resources may include understandable and available information, practised evacuations, and having skills and assets that allow self-sufficiency and that allow adaptiveness.

Risk is defined by UNISDR as ""The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity." (2017). This can be expressed as; Risk = likelihood x (Hazard x Exposure x Vulnerability) (Figure 1.1).

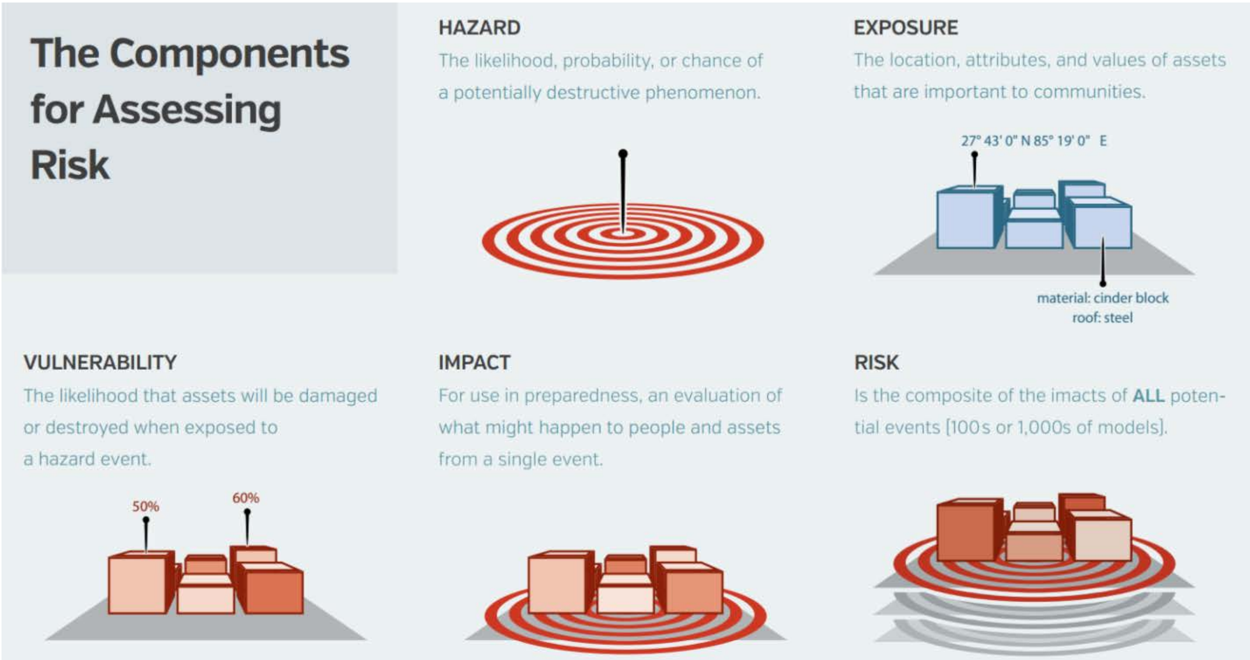

Figure 1.1. The components for assessing risk; hazard, exposure and vulnerability. This figure also describes the difference between impact and risk. Retrieved from GFDRR, (2014, p.21).

The magnitude of a hazard (such as the size of an earthquake, landslide or tsunami) cannot be reduced; therefore disaster risk and disaster impacts can be mitigated by understanding the likelihood and magnitude of hazards, reducing exposure and vulnerability as well as building capacities (PreventionWeb, 2014). This understanding became widely recognised post-millennium, and the term disaster risk reduction was coined.

Disaster Risk Reduction (DRR) *is* "the policy objective of anticipating and reducing risk" (PreventionWeb, 2015). DRR is implemented through disaster risk management (DRM) which describe the actions taken to eliminate, mitigate or reduce risk and/or impacts (PreventionWeb, 2015; 1.2). Successful DRR is fostered by integrating local and indigenous knowledge, interdisciplinary scientific and institutional: commitment, knowledge, experience and resources in a culturally compatible manner (Mercer, Dominey-Howes, Kelman, & Lloyd, 2007; Gaillard & Mercer, 2013; PreventionWeb, 2015; Davies, 2015; Figure 3).

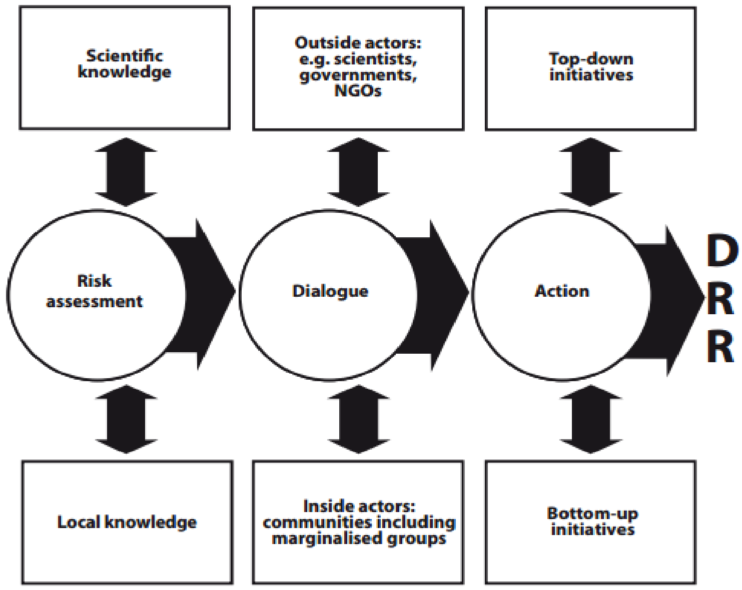

Figure 1.2. Schematic diagram showing the integration of knowledge, actions and stakeholders in DRR. Retrieved from Gaillard & Mercer, (2013, p.95).

Resilience is "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management" (UNISDR, 2017).

1.3.2 Global DRR

The United Nations Office for Disaster Risk Reduction (UNISDR) coordinates international efforts in DRR, provides a hub for information exchange through the Global Platform for DRR and supports the implementation, follow-up and review of the Sendai Framework for DRR. The Sendai Framework for Disaster Risk Reduction 2015-2030 (which followed the Hyogo Framework for Action 2005-2015) seeks to achieve "substantial reduction of disaster risk and losses in lives, livelihoods and health and the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries" over 15 years (UNISDR, 2015-2030). The Sendai Framework advocates for national governance structures and stakeholder platforms to integrate ongoing DRR over time and provides guidance for incorporating risk science into disaster reduction policy and strategies (Beaven, 2015). The four priorities of the Sendai Framework are;

i. "Understanding disaster risk;
ii. Strengthening disaster risk governance to manage disaster risk;
iii. Investing in disaster reduction for resilience and;

iv. Enhancing disaster preparedness for effective response, and to "Build Back Better" in recovery, rehabilitation and reconstruction" (UNISDR, 2015-2030, p.14).

Integrated Research on Disaster Risk (IRDR), (co-sponsored by UNISDR, International Council for Science (ICSU) and the International Social Science Council (ISSC)) is an international research programme that runs parallel to the Sendai Framework (IRDR, n.d). The programme is tasked with nurturing more multidisciplinary hazard and disaster research that integrates the needs of both policymakers and stakeholders. The programme was formed to help bridge the increasing gap between scientific advances and society's ability to capture new knowledge and implement it into initiatives to reduce disaster impacts (Beaven, 2015).

This thesis seeks to contribute to Sendai priorities i) understanding disaster risk and iv) enhancing disaster preparedness; it follows a multidisciplinary approach to integrate the needs of both the community and government agencies tasked with implementing DRR.

1.3.3 DRR in New Zealand

New Zealand is recognised internationally for 'good practice' in DRR due to its long history of applied effort over the 4R's; reduction, readiness, response and recovery, and to increase resilience (NZLG, 2014). This is due to effort and investment in: assessments to identify, evaluate and treat risk and impact, community awareness campaigns, early warning systems, response and recovery legislation and local government capacity building (MCDEM, 2015). In March 2015, the Government of New Zealand made a commitment to the International Sendai Framework for Disaster Risk Reduction following the expiry of the Hyogo Framework for Action, to which New Zealand was also committed (MCDEM, 2016b).

The statutory landscape that drives DRR in New Zealand to achieve the goals mentioned above is shown in Figure 1.3. Effective DRR is dependent on the interplay between a range of statutes and diverse groups. Legislation that governs DRR in New Zealand includes the Civil Defence Emergency Management Act 2002 (which encompasses the National CDEM Strategy, National CDEM Plan and CDEM group plans), the Resource Management Act 1991, the Building Act 2004, the Local Government and Official Information and Meetings Act, the Local Government Act 2002 and the Soil Conservation and Rivers Control Act 1941 (LGNZ, 2014).

DRR is then physically implemented by a diverse group of players including: the Ministry of Civil Defence and Emergency Management, the Ministry for the Environment, the Ministry for Business Innovation and Employment, the Department of Conservation, the Earthquake Commission, the National Infrastructure Unit (within Treasury), Regional councils, Territorial authorities, Crown Research Institutes (CRIs), the Natural Hazards Research Platform, CDEM groups, infrastructure lifelines groups, universities, commercial players such as insurance companies, reinsurers, and banks, as well as community groups, households and individuals (LGNZ, 2014).

Figure 1.3. The CDEM Framework that Implements the 4R's to Build Resilience. Retrieved from MCDEM (n.d). The green dashed box indicates the level this thesis contributes to.

The International Federation of Red Cross and Red Crescent Societies (2014), commenting on A-NZ DRR, note that the

> *"different legislative statutes are well-integrated, but the challenge lies in reflecting this integration in implementation. Continued work and investment is required for implementation to fully succeed, notably in hazard-prone areas with a small population base, where resources for DRR are based on local taxes (rates) rather than local risk levels. To fully realise the potential that New Zealand DRR legislation affords, there is also a need to increase capability and the sharing of information along with collaborative strategies, behavior and approaches between central and local government, the private sector and communities,"* (p.5).

Currently (2018), the Ministry of Civil Defence and Emergency Management is drafting the National Disaster Resilience Strategy which will replace the National Civil Defence and Emergency Management Strategy with a focus change from ‘managing disasters’ to ‘managing risk’ (MCDEM, n.d-a). National strategies set out the principles and goals that guide all CDEM stakeholders and DRR players (MCDEM, n.d-a).The strategy’s byline - ‘New Zealand working together to reduce risk and build resilience,’ - suggests that information sharing and collaborative strategies will be a core component.

1.3.4 Community Participation in DRR

Arnstein (1969) illustrates levels of citizen participation as rungs of a ladder (Figure. 1.4), which indicate the amount of power and control that participants have in decision making, processes and shaping outcomes. These rungs progress from non-participation, to tokenship to citizen power; the highest form of community participation.

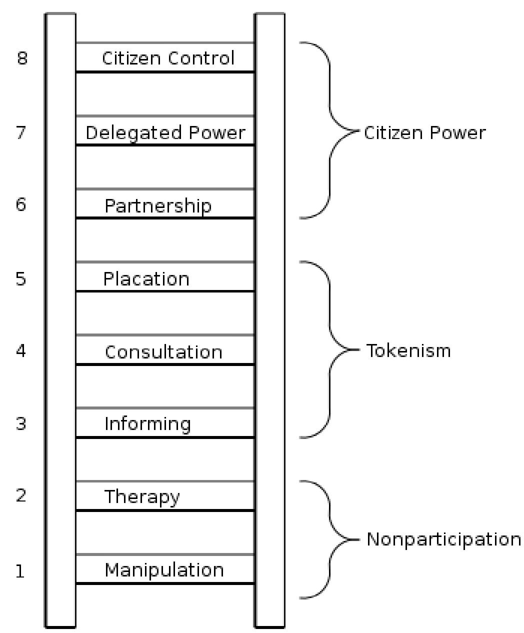

Figure 1.4. A ladder of participation, retrieved from Arnstein, (1969, p.217).

Engagement is a form of consultation, categorized as tokenship by Arnstein (1969). As Healy (1992) describes “citizens contribute to the process, but only by ‘feeding in’ their rationalized goals, rather than debating the understandings through which they come to have their goals” (p.250).

Participation involves partnership, delegated power and citizen control whereby two-way dialogue and knowledge sharing and are the top rungs of citizen participation, enhancing citizen power over decisions, processes and outcomes.

While Central and Local Government have an overall responsibility for guiding and implementing DRR initiatives in New Zealand, the responsibility is also shared with stakeholders. “Stakeholder commitment, goodwill, knowledge, experience and resources” play an important role in implementing DRR initiatives (UNISDR, 2015-2030, p.23). This thesis seeks to contribute towards Sendai priorities: i) understanding disaster risk and iiii) enhance disaster preparedness for the Chatham Islands, New Zealand. According to the Sendai Framework, to understand disaster risk, it is important to “enhance collaboration among people at the local level to disseminate disaster risk information through the involvement of community-based organizations and nongovernmental organizations” (UNISDR, 2015-

2030, p.15). To achieve priority iiii); enhancing disaster preparedness, it is important to "facilitate, as appropriate, the participation of all sectors and relevant stakeholders…, develop systems through a participatory process; tailor them to the needs of users, including social and cultural requirements…, and to promote the cooperation of diverse institutions, multiple authorities, and related stakeholders at all levels including affected communities and businesses" (UNISDR, 2015-2030, p.21).

1.3.4.1 Why involve communities in DRR?

Over the last few decades, considerable attention has turned to community-based DRR (CBDRR) as practitioners advocate for participation of those who are directly affected by disasters and who possess valuable local knowledge (of their hazards, exposure, vulnerability and capacity) in DRR decision-making processes (Maskrey, 1989; Twigg 1999; Pelling, 2007; Heijmans, 2009; Gaillard & Mercer, 2013 and others). As Gaillard & Mercer (2013, p.98) state:

1. During a disaster, it is the community that is directly impacted and first to respond
2. No one is more interested in reducing risks than the people who are likely to be impacted by a disaster
3. Nobody can understand local opportunities and challenges better than local people themselves

Participatory DRR empowers both communities and local authorities to reduce vulnerability and strengthen capacity, and ensures initiatives are well-informed, resourced and more effective (Hyogo Framework for Action 2005–2015, as cited by Pelling, 2007).

1.3.4.2 Participatory Methods and Tools

Methods and tools are being trialed and developed by humanitarian aid workers, researchers and practitioners to guide and facilitate community participation to allow "effective application of the [local] knowledge about vulnerability aspects, needed for successful implementation of DRR measures" (Løvholt et al., 2014, p.17; Chambers, 1994; Tompkins & Adger, 2004; IFRC, 2006; Schoch-Spana, Franco, Nuzzo, & Usenza, 2007; Benson et al., 2007; Mercer, Kelman, Lloyd, & Suchet-Pearson, 2008; Gaillard 2010; Cadag & Gaillard, 2012; DRR Working Group, 2012; Gaillard & Cadag, 2013; Gaillard et al., 2013; Healy et al., 2014; Henly-Shepard, Gray & Cox, 2015; Amirapu, 2016; Gaillard et al., 2016; Baudoin, 2016; and others).

Participatory learning and action (PLA) involves a suite of approaches to enable local stakeholders to analyse information, to plan and to act; and is a process from, with and by the community (Chambers, 1994). Participatory learning and action allows effective, locally-specific planning and action, designed by stakeholders who have ownership of these plans, to be carried out, and thus are more likely to carry them out than if they were excluded from the process (Healy et al., 2014; Mercer et al., 2008; Tompkins & Adger, 2004; Schoch-Spana et al., 2007).

Hazard, vulnerability and capacity analysis (HVCA) involves PLA and "is an investigation that uses various participatory tools in order to understand the level of exposure to (and capacity to resist) natural hazards at grass-roots level... it can contribute to the creation of community-based disaster preparedness programmes at the rural and urban grass-roots level and is a tool which enables local priorities to be identified and leads to the design of actions that contribute to disaster reduction" (IFRC, 2006, p.21). In summary, HVCA can be used as a planning tool to prioritise and sequence actions and inputs and can empower and mobilise vulnerable communities (Benson et al., 2007). A wide range of environmental, economic, social, cultural, institutional and political pressures that influence vulnerability can be identified and evaluated through HVCA, that would not normally be understood by external researchers (Benson et al., 2007). "A clear picture of what is and who are at risk, and the availability of resources and capacities to mitigate these natural hazards, provides a solid basis for planning," (Cadag & Gaillard, 2012, p.105). A list of tools and activities that have been used by NGO's to carry out HVCA are provided in Appendix G.

1.3.5 The Risk Management Framework

The risk management approach is used globally for assessing tsunami risk (Dominey-Howes and Goff, 2013; Jelínek et al., 2012; Papadopoulos and Dermentzopoulos, 1998). Best practice risk management approaches incorporate community participation throughout this process. The AS/NZ:31000 Risk Management Framework is a standardised process used to assess and mitigate natural hazard risk in New Zealand, used by local authorities, CDEM groups, infrastructure lifeline agencies, research institutes and the private sector (Figure 1.5). The AS/NZ:31000 Risk Management Framework sets the conceptual framework for this thesis. Each step of the framework/process is described below.

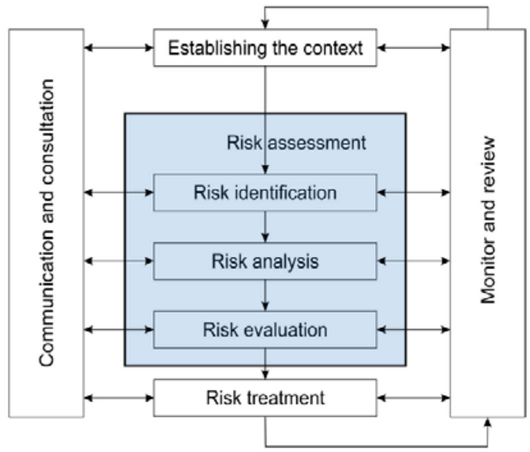

Figure 1.5. AS/NZS ISO 31000:2009 Framework for Risk Management. Retrieved from AS/NZS (2009).

1.3.5.1 Establishing the Context

Here, organisations and stakeholders set goals and identify internal and external parameters for consideration. The context was established by engaging with local community groups and organisations as well as local and regional government to evaluate past, present and future DRR initiatives and to identify areas for further investigation of use to the community. The aims and objectives of this thesis followed from establishing the context (AS/NZS, 2009; Section 1.4).

1.3.5.2 Risk Assessment

Risk assessment then follows, encompassing risk identification, risk analysis and risk evaluation. The most appropriate tools and techniques (methods), that are best suited to the objectives of the assessment, and up-to-date data, should be used in the risk assessment process. Personnel with expertise, skills and local knowledge in subject areas involved in risk identification, analysis and evaluation should be involved (AS/NZS, 2009).

1.3.5.2.1 Risk Identification

In the context of this research, risk identification involves:

- identifying tsunami hazard frequency and magnitude by reviewing literature and investigating historical tsunami events (Chapter 3),
- identifying exposed societal assets, which for this study, includes infrastructure assets such as electricity, communications, water, transportation and sewerage assets (Chapter 5),
- recognising how vulnerable these assets may be and how they might be impacted by reviewing literature from past tsunami events around the world (Chapter 2).
- identifying, reviewing and monitoring constraints and limitations.

1.3.5.2.2 Risk Analysis

Risk analysis involves gaining a deeper understanding to determine the level of risk and informs decisions in risk evaluation and treatment. “Risk analysis involves consideration of the causes and sources of risk, their positive and negative consequences, and the likelihood that those consequences can occur. Factors that affect consequences and likelihood should be identified,” (AS/NZS, 2009, p.18).

Impact assessments can be probabilistic and/or deterministic and can utilise qualitative, semi-quantitative and/or quantitative data inputs, each of which have their pros and cons (Table 1.1). Probabilistic assessments are based on quantitative methods that determine the probability of an event occurring and estimates the magnitude of an event, using probability distributions to represent a range of events that may occur. Quantitative analysis can be used to compare and contrast various events and may be used to conduct cost-benefit analysis when determining optimal impact reduction measures (Power, 2013a). However, probabilistic assessments are limited by large uncertainties and assumptions involved in assessing infrequent, large magnitude events that modern (post-colonisation) New Zealand has little experience of (Davies, 2015). As Davies, (2015) states, probabilistic assessments are useful for mitigating risk of frequent, small magnitude events in a particular location but are “unreliable for planning local (or community) resilience to naturally triggered disasters, because the number of such events that will affect a given community in any realistic planning time frame is very small, so event occurrence is unlikely to reliably match probability,” (p.237).

Table 1.1. Pros and cons of qualitative, semi-quantitative and quantitative data inputs for impact assessments. Retrieved from Scheele (2016) and Power, (2013a)

Methodology	Pros	Cons
Qualitative	Can be based on sparse or coarse data; efficient	Relatively subjective; cannot easily be used to compare events
Semi-quantitative	Improves on qualitative by adding scores/rankings	Requires more data than qualitative assessment
Quantitative	Used for deterministic or probabilistic modelling; provides in-depth information; can be used for cost-benefit analysis	Data intensive; results depend heavily on quality of input data

Deterministic, scenario-based assessments use quantitative and/or qualitative methods to evaluate the consequences of a modelled or historical hazard scenario. These scenarios are often chosen to represent a worst-case scenario to evaluate potential impacts to inform preparedness, response and recovery initiatives. However, these only represent one given scenario and are not representative off all possible events that could occur. Thus, better practice in this method could involve using multiple scenarios from all potential sources to represent the range of events that may occur.

Risk analysis also involves consideration and communication of the likelihood that these impacts may occur and limitations in the assessment to stakeholders and decision makers.

1.3.5.2.3 Risk Evaluation

Risk evaluation involves determining whether the risk or impacts are acceptable, tolerable or unacceptable to stakeholders and decision makers, to determine what actions could be taken to reduce impacts and therefore risk (AS/NZS, 2009).

1.3.5.3 Risk Treatment

After the risk assessment has been carried out with consultation, communication, monitoring and review involved in all steps of the process, various risk/impact mitigation strategies are evaluated, some are selected, and their performances are monitored and reviewed over time (AS/NZS, 2009). Impacts, and therefore risk, can be avoided or reduced through implementation of mitigation strategies informed by the risk assessment process and developed with stakeholders and decision makers. Risk treatment options may include;

- avoiding impacts/risk by reducing exposure (relocating assets, changing land-use rules),
- reducing impacts/risk by reducing vulnerability (structural mitigation, increasing readiness and preparedness),
- reducing impacts/risk by increasing hazard monitoring or investing in better hazard detection and warning technologies to initiate actions such as evacuations and relocating assets (AS/NZS, 2009).

1.3.5.4 Communication and consultation

Communication and consultation with all stakeholders should be involved during all steps in the framework. Exchange of information and mutual understanding between stakeholders and the agency following the framework fosters credible risk assessment and useful and usable risk treatment options (AS/NZS, 2009; Section 1.2.3).

1.3.5.5 Monitor and Review

Both monitoring and review should also take place at all steps in the process to ensure the assessment is robust and credible for a better means to evaluate and mitigate risk (AS/NZS, 2009). It is important to regularly review new literature, data, methods, lessons and failures to improve the risk assessment. It is also important to monitor changes in the environment (e.g. new risk reduction initiatives, changes in politics, demographic changes, a hazardous event, development of new assets and new hazard information) that may change the context or the risk itself, which would then require review of risk treatment options and re-prioritisation. Monitoring and reviewing changes in the environment also helps identify any emerging risks.

1.4 The Chatham Islands – Setting the Context

Wharekauri-Rekohu-Chatham Islands are located approximately 800 km east of Aotearoa-New Zealand (A-NZ) and included two inhabited islands, Chatham and Pitt Islands (Figure 1.6). Chatham and Pitt Islands have a combined population of approximately 600 people, of which, 59.3% identify as being Māori, with the remainder mostly identifying as being European or Pacific Islanders (Statistics New Zealand, 2013). The predominantly fishing and farming community is tight-knit, due to a small population living in isolation, strong inter-generational relationships, shared history and culture, over time, people of various ethnicities “intermarried to become ‘Chatham Islanders’, fiercely loyal to one another in the face of threat, death or disaster” (Richards, n.d). Chatham Islanders live in close association with their environment, as their livelihoods depend on it, as a result some people on the island obtain rich local knowledge of Chatham Islands history from stories past down.

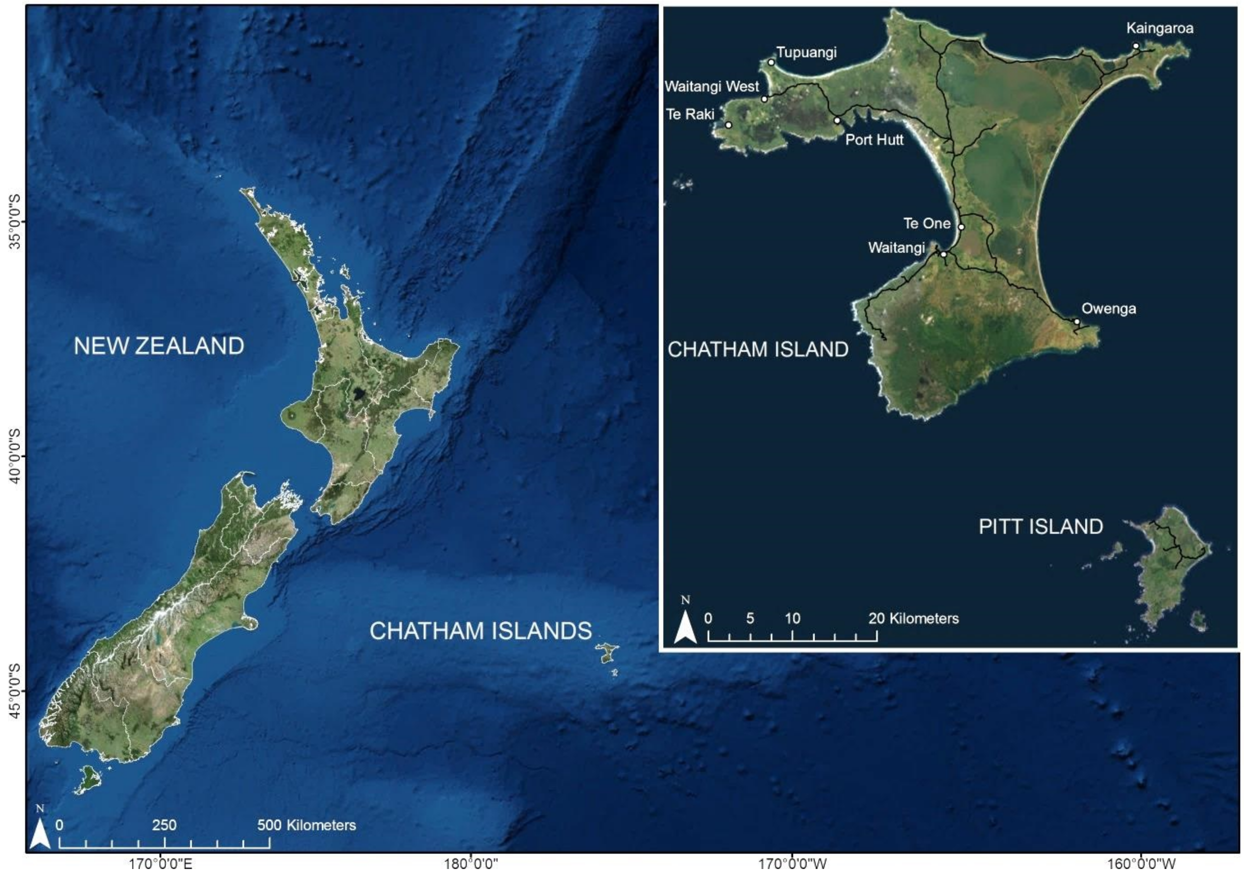

Figure 1.6. Map of the Chatham Islands, New Zealand. Data sourced from Stats NZ Geographic Data Service (2017), LINZ Data Service (2018), and ESRI (2013).

The operation of every-day-life in the Chatham Islands, and the economy, are dependent on functioning infrastructure components and essential services. The Chatham Islands contribute approximately $200 million to the New Zealand economy per annum. In 2016 there were “448 filled jobs on the Chatham Islands generating $47 million in GDP” (Leung-Wai & Borren, 2017, p.24). The biggest industries on the Chatham Islands are fishing, farming, transportation and tourism as well as government and public services. The fishing sector is the largest industry; in 2016 it provided 135 jobs and generated $18.5 million in GDP. This is followed by farming which provided 62 jobs and generated $4.8 million in GDP; transportation which provided 40 jobs contributing $4.4 million in GDP; and tourism which employed 38 people and contributed $2 million to the Chatham Islands economy in 2016 (Leung-Wai & Borren, 2017).

The fishing, farming and tourism industries are dependent on:

- Potable water (for drinking and cleaning), and unpolluted sea water (for ice and live wells to keep fish alive before processing).
- Internal (on-island) and external (off-island) communications.

- Operation of sea and air ports and the arrival and departure of cargo ships and planes (to export products to New Zealand and Internationally as well as for delivery of food/supplies/equipment).
- Fuel (particularly diesel) for factory generators, fishing vessels, transportation vehicles and heavy machinery.
- Electricity to operate factories and to provide for tourists.
- Roads and bridges on the island to transport goods from plant/farm to plane or ship as well as for workers and tourists to travel.
- Environmental conditions such as weather and tides (restricts shipping and air transport as well as whether people can go fishing).

The Chatham Islands, New Zealand, are exposed to local, regional and distal source tsunamis and have a history of destructive and fatal tsunami events (Thomas, 2017). Coastal communities on Chatham Island include Waitangi, Te One, Owenga, Kaingaroa and Port Hutt. These townships all occupy low elevation areas proximal to the coast. Thus, infrastructure components and facilities (including transportation corridors, electricity, communications, water and sewerage) in these locations may be at risk to tsunami impact. Key dependencies on infrastructure and essential services poses some challenges for the isolated setting. During a high-impact tsunami the Chatham Islands may be isolated from external assistance for some period of time.

1.5 Research Methodology & Thesis Structure

The methodology used in this thesis follows the international standard Risk Management Framework, but with community participation central to the process to co-create options to reduce potential tsunami impacts that are useful to and usable by the Chatham Islands community. The research pathway begins with collation of information, then combines the information with co-developed knowledge to generate a shared-evidence base for action to engender community-led action to reduce tsunami impact (Figure 1.7). Five chapters detail these processes following risk identification, analysis, and evaluation to derive impact reduction options. This thesis is not strictly linear, but recursive within itself.

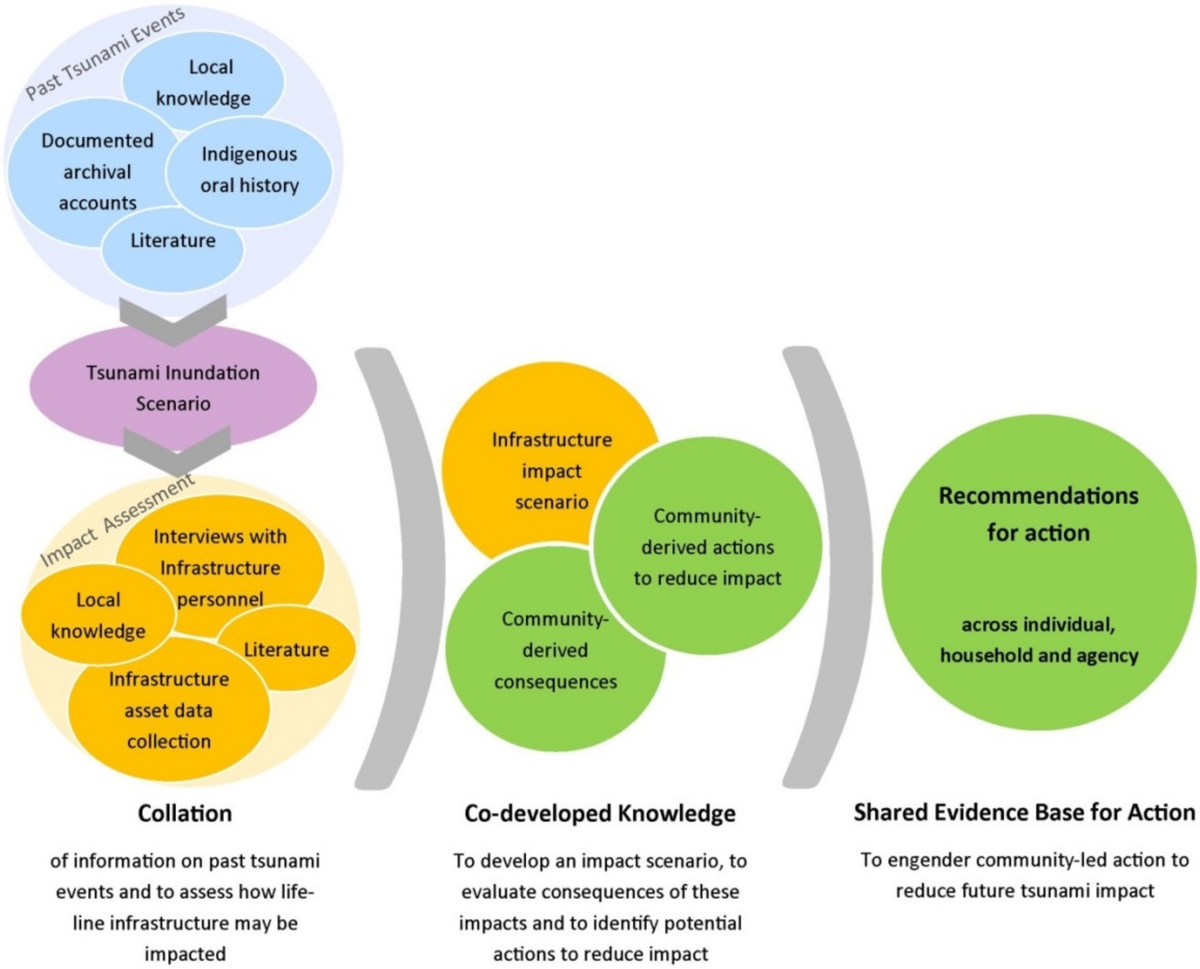

Figure 1.7. Thesis research pathway. The different colours represent subsequent chapters. Chapter 3 - blue, chapter 4 - purple, chapter 5 - orange and chapter 6 green.

Chapter 2 establishes the context for this study by outlining past, current and future risk reduction initiatives and information requests from the community which drove the research aims and objectives of this thesis. The risk identification process also begins in this chapter with a literature review of tsunami hazard for NZ and the Chatham Islands, Māori knowledge of tsunami hazard, available tsunami inundation models for the Chatham Islands, and impact assessment methodologies including vulnerability models for infrastructure.

In Chapter 3 (blue), the risk identification process is continued with investigation of past tsunami inundation extents and impacts on the Chatham Islands recorded in oral history and documented accounts. Current inundation models for the Chatham Islands appear to underestimate inundation extent compared to historical accounts. Thus Chapter 4 (purple) describes the methods involved in selecting and forming a credible and appropriate hazard scenario – and its derived footprint - to be used for the impact assessment. Uncertainties and limitations of the methods involved are discussed, as are recommendations for future research.

Chapter 5 (orange) details the risk analysis stage. A combination of probabilistic and deterministic approaches were used to analyse potential tsunami impacts on Chatham Islands infrastructure to evaluate loss of services. As digital infrastructure data for the Chatham Islands were sparse, an asset database including location of hotspots, pinchpoints and criticality of network lines was generated, informed by expert judgment, field investigations and local knowledge. The hazard scenario footprint, a combination of deterministic and probabilistic inundation extents and depth, was overlaid with infrastructure datasets to identify exposed assets. As tsunami vulnerability models for infrastructure were not widely available or appropriate for all assets (Williams, 2016), a damage matrix was applied to determine likely damage states. The resultant damage states were then used, assisted by expert judgment, to infer the level-of-service (LoS) that could be expected from a network following impact. Uncertainties and limitations of the methods involved in this impact assessment were discussed, as were recommendations for future research.

Chapter 6 (green) details the methods involved for the participatory community workshops, facilitated to share information of the previous chapters with the community; to discuss the credibility of the historical information and impact scenario (monitoring and review); and to draw out a deeper understanding of how loss of services following tsunami impact may affect the community (further risk analysis) in order to evaluate community-derived impact reduction initiatives (risk treatment). The impact assessment provided the scenario used as the basis of the workshop activities which co-developed knowledge and provided an opportunity to better understand the community's capacity (or strengths) to respond and recover from a tsunami event. It also identified gaps that require attention to better prepare and strengthen community resilience. This is this crucial step that is intended to engender community-led action to reduce tsunami impact.

2 LITERATURE REVIEW

2.1.1 Introduction

A literature review was carried out to inform the methods used in the following chapters. This Chapter addresses objectives 1 and 4; to review literature of Māori indigenous knowledge of tsunami, Māori research methodologies and terminology, as well as to review literature and case studies of tsunami impact assessments for infrastructure and loss of services including available tsunami vulnerability models. Firstly background information on tsunami, their behavior and damage styles is provided before reviewing literature on tsunami hazard in New Zealand and the Chatham Islands. The process of carrying out a tsunami impact assessment is detailed and an overview of tsunami risk management in New Zealand, including initiatives contributed to the Chatham Islands, is provided.

2.1.2 Tsunami Background

2.1.2.1 What is a Tsunami?

Tsunami result from the rapid displacement of a water column (in a sea or lake). This displacement can be caused by a coastal or submarine earthquake, a landslide (submarine or coastal/lakeside), a volcanic eruption or a meteorite impact (Berryman, 2005; Power, 2013). Disturbance of the entire water column generates a series of waves that radiate from the source, the size of the tsunami generated depends on the size of the trigger.

Even the largest tsunami waves have typically less than 1 m amplitude in deep ocean water (Berryman, 2005). As the waves move closer to shore they slow down, increasing the height and amplitude of the wave and reducing their wavelength (Figure 2.1). Tsunami waves behave differently to wind-derived ocean waves. Wind-derived waves cause water to follow a circular motion and only displace particles in the top section of the water column; whereas tsunami waves are driven in one direction by the entire water column (Figure 2.2). "The distance between successive [tsunami] waves (called wavelength) can vary from several kilometres to over 400 km, rather than around 100 metres for normal waves at the beach," and tsunami waves can travel at speeds of 500km/h in deep water (Berryman, 2005, p.6). Therefore, tsunami waves can arrive at their destination minutes to hours part and often arrive without complete retreat of the previous wave. The first tsunami wave may not be the largest, and may be negative (i.e. the water initially recedes).

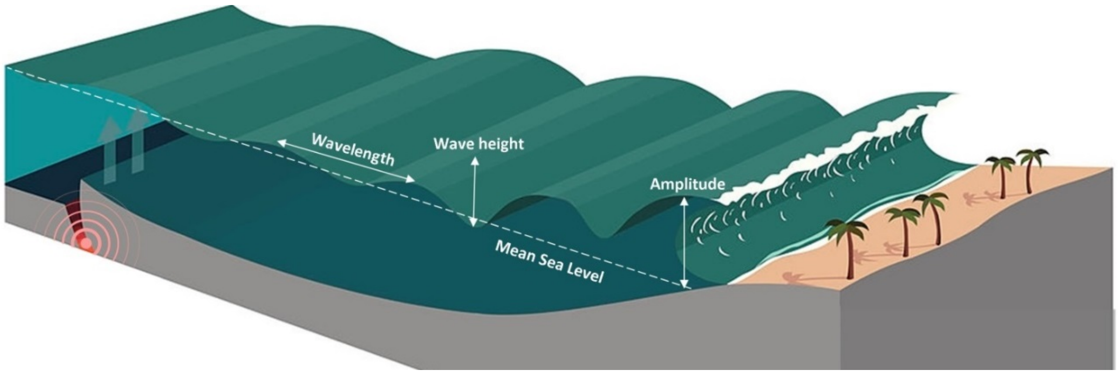

Figure 2.1. Tsunami wave generation and arrival of waves at the shore with labeled tsunami terms. Adapted from Getty Images (n.d).

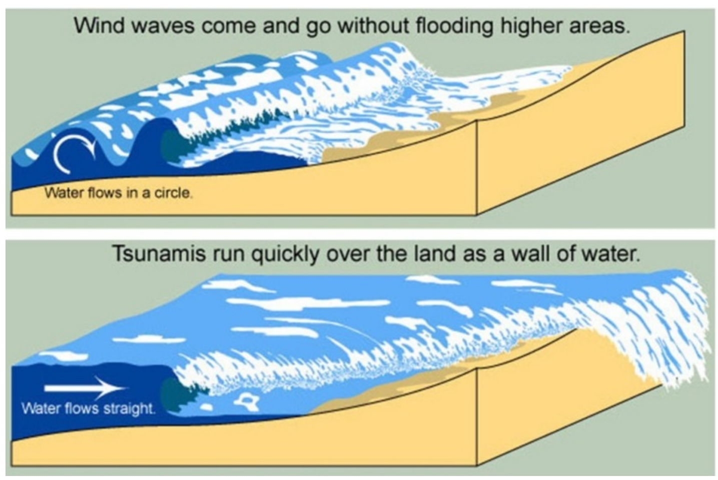

Figure 2.2. Comparison of wind-derived ocean waves and tsunami waves. Retrieved from Shiro, 2015.

2.1.2.2 Tsunami Behavior

Tsunami are powerful and highly complex. Observations of recent tsunami impacts including the 2004 Indonesian tsunami, the 2011 Tohoku tsunami, the Chile 2010 tsunami and the 2015 Illapel tsunami have provided better understanding of tsunami behavior and damage to physical assets including buildings and infrastructure (Williams, 2016; Scheele, 2016).

Tsunami damage can be classed as primary or secondary impacts (Power, 2013). Primary impacts are caused by hydrostatic (inundation) and hydrodynamic (fast flows that cause erosion, soil instability and scouring) forces (Horspool & Fraser, 2016). Secondary impacts include those caused by carried, dragged and buoyant debris during incoming and receding flows. Salt-water contamination and fire can also be secondary impacts (Power 2013; Horspool & Fraser, 2016).

When evaluating potential tsunami impacts on infrastructure it is important to understand that primary and secondary impacts vary spatially (Williams, 2016). Where, how far inland, how deep and how fast a tsunami inundates depends on the characteristics of waves arriving at the shoreline, which in turn depends on a variety of factors; the amount of displaced water column (related to earthquake, landslide or eruption size/displacement), the distance from the tsunami source (energy loss), bathymetry, orientation of coastline, tide cycle, topography and land surface (Lane, Gillibrand, Arnold & Walters, 2011; Selvakumar & Ramasamy, 2013) (see Appendix B for tsunami terminology).

Bathymetry (shape of the sea floor) and coastline orientation can direct waves into harbours through wave reflection and refraction. Waves can also be amplified if they resonate with normal on-shore waves. “A tsunami wave that has energy with a similar period to the natural period of a harbour or bay will have a much larger impact” (Lane et al., 2011, p.85). If tsunami waves inundate land, their behaviour is affected by topography and land surface types. Local geomorphic features such as sand dunes, cliffs and thick vegetation restrict inundation (but often generate higher run-up), whereas low-lying areas such as tidal flats, estuaries and river inlets experience greater inundation extents (Chandrasekar & Ramesh, 2007). Inundation and saltwater contamination can cause minor to major impacts on infrastructure (Power, 2013).

Topography, land surface (particularly location of structures) and entrained debris influence the hydrodynamic force of a tsunami by affecting flow depth and/or velocity. Hydrodynamic pressures include buoyancy, horizontal drag and erosion (scouring) which occur during both advancing and retreating flows (Power 2013). As an example, narrow channels influenced by topography, urban streets or debris blocks can increase velocity so that greater hydrodynamic forces are experienced generating greater impacts on exposed assets.

Post-tsunami observations show that debris (which could include boulders, trees, fishing vessels, parts of houses and vehicles) entrained in tsunami flow can cause major damage to infrastructure assets. Debris density and load in tsunami flows generally increases with distance inland as more objects are damaged and carried with the flow (Horspool and Power, 2016). According to Evans (2011), flows deeper than 2 m carry most objects: houses, cars, storage tanks etc. Flows shallower than 1 m tend to suspend light vegetation, buoyant objects, silt and sand. In flow depths of 1 – 2 m cobbles and wooden debris are common.

Soil instability generated by scour, subsidence and/or liquefaction during tsunami back-flow can also cause major damage to infrastructure (Yeh, Sato & Tajima, 2013; Williams, 2016).

2.1.2.3 Tsunami Impacts on Infrastructure

The following Section compiles information available on tsunami impacts on each of the following infrastructure types applicable to the Chatham Islands. It builds from Section 2.1.2.2 which provides a basic review of tsunami damage styles and behavior. The information reviewed here is based on empirical data from damage surveys conducted following tsunami events in the past, including: Indian Ocean 2004, Samoa 2009, GEJ 2011, Chile 2010, Illapel 2015.

2.1.2.3.1 Transportation

2.1.2.3.1.1 Tsunami Impacts on Roads

Scour and debris damage are the primary cause of road damage during tsunami events resulting in reduced LoS (Horspool & Fraser, 2016; Figure 2.3). Debris damage to roads is usually superficial, requiring clean-up of deposits, but if roads are located in poorly drained areas; clean-up efforts can be delayed due to ponded water that can remain for days and prevent road usage (Horspool & Fraser, 2016). During the 2015 Illapel (Chile) Tsunami, most structural road damage was observed near the coast where pipes/culverts/drainage channels intersected the road. Further from the coast, minor peeling or deterioration of the road surface was observed (Horspool & Fraser, 2016).

Figure 2.3. Tsunami damage to roads. Left: debris cover a road in Iwate Prefecture, Japan (Taylor, 2011). Right: structural damage to a coastal road from the 2015 Illapel tsunami, Coquimbo, Chile (photo from James Williams).

"Roads that are most vulnerable [to tsunami damage] are those:

- located near the shoreline,
- located adjacent to drainage channels/rivers/culverts/pipes,
- located on elevated ridges,
- are formed of asphalt laid on a poorly compacted base," (Horspool & Fraser, 2016, p.11),
- are in areas of low surface roughness (Francis, 2006),
- and that have been subjected to a greater number of waves, higher flow velocities and severe inundation depths (> 2 m) (Horspool and Fraser, 2016; Shoji, Nakamura & Takahashi, 2012).

Other infrastructure such as buried or overhead cables and pipes are often located parallel or intersect road networks. Therefore, tsunami damage to roads such as scour and collapse can also result in damage to these other services (Horspool & Fraser, 2016).

2.1.2.3.1.2 Tsunami Impacts on Bridges

Bridges are one of the most vulnerable built assets to tsunami due to their location over waterways where higher flow rates occur (Horspool & Fraser, 2016). Bridges also often carry other infrastructure such as telecommunication cables, water pipes and electricity lines; thus, failure of these structures can cause cascading failures (Pescaroli and Alexander,2016). Tsunami impacts on bridges include:

- Scouring and erosion around abutments, wing walls and piers.
    - o Scour and erosion nearly always occurs (Evans, 2011; Horspool & Fraser, 2016; Horspool & Fraser, 2016). Bridges that have deep foundations are less vulnerable to sour damage but in most cases scour does not prevent bridge operation and requires minor repairs to infill lost material (Horspool & Fraser, 2016).
- Minor to moderate damage to bridge superstructure (Figure 2.4).
    - o This damage is mostly caused by debris strikes. Debris strikes usually only cause superficial damage to attached services, rails and footpaths. However structural damage from large debris strikes was recorded during the 2004 tsunami in Banda Aceh (Iemura, Pradono, & Takahashi, 2005).
- Complete washout of bridge superstructure (Figure 2.4).
    - o When tsunamis inundate both the bridge deck and superstructure, hydrodynamic (lateral), buoyancy (vertical) forces and debris impact can cause significant damage including complete washout (Kosa, 2012).

Reinforced concrete bridges in Japan (GEJ 2011 tsunami) and Sumatra (2004) were less damaged than steel or steel truss or timber bridges which were more susceptible to debris damage (Kosa, 2012; Chock et al., 2013).

Figure 2.4. Tsunami damage to bridges. Left: The GEJ tsunami washed the whole superstructure of a bridge away (Bravo, Yen & Vélez, 2015). Right: GEJ tsunami debris cover a bridge in Ishinomaki, Japan (BBC News, 2012).

2.1.2.3.1.3 Tsunami Impacts on Ports

Ports are susceptible to damage from both inundating and non-inundating tsunamis (due to being exposed to effects of strong currents) (Wilson et al. 2013; Borrero et al. 2015; Horspool & Fraser, 2016; Turnbull & Hughes, 2017). Tsunami impacts on ports include superficial and structural damage to:

- Wharf piles:
    - The base of wharf piles can be scoured during strong currents and high flow velocities, this increases the chance of wharf collapse (Borrero et al. 2013; Wilson et al. 2013; Borrero et al. 2015a). Piles are also susceptible to damage from debris strikes, debris damming (piling up of debris), hydrodynamic forces and fire from waterborne flammable materials (PIANC 2010; Wilson et al. 2013; Borrero et al. 2015; Turnbull & Hughes, 2017).
- Wharf decks:
    - Wharf decks can be lifted off their piles due to buoyant force, sheared off their piles or footings by hydrodynamic forces, and damaged by debris strikes during both advancing and retreating flows. Damaged parts of the deck may then be carried away due to hydrodynamic forces (PIANC 2010; Wilson et al. 2013; Chock et al., 2013; Ewing et al. 2013; Borrero et al. 2015; Turnbull & Hughes, 2017).

- Wharf buildings:
    - Wharf buildings are highly exposed to tsunami damage due to their coastal location. Structural damage can occur due to; buoyant forces uplifting buildings off their foundations, being carried away by hydrodynamic forces, scouring around the base of foundations and debris impacts. Building contents are also susceptible to inundation causing failure of mechanical and electrical. Light steel and timber structures are more susceptible to damage than reinforced concrete structures (Okal et al., 2002; Okal, Sladen & Okal, 2006; Chock et al., 2013; Borrero et al., 2015).
- Sea walls and breakwater structures:
    - Scour around the base of seawalls and breakwater structures threatens the structural integrity of the structure, the structure can tilt or rotate due to scour and hydrodynamic forces and components can be washed away by buoyant and hydrodynamic forces. In Japan substantial breakwaters and sea walls collapsed and caissons were scattered around the harbour (Ewing, Takahashi & Petroff, 2013; Ohira et al., 2014). These structures can also be structurally damaged by debris impact (PIANC 2010; Chock et al., 2013; Ewing et al. 2013).
- Fishing Vessels and equipment:
    - Vessels may hit the bottom of the harbour when waters receive causing damage. Vessels moored to wharf structures may drift or rotate due to hydrodynamic forces and cause collision with structures and other vessels. In high velocity flows mooring lines can snap due to tension as the water level rises and falls, or by debris impact (PIANC, 2009; Wilson et al. 2013). Large tsunami waves can exceed mooring lengths, moorings can restrict the vessel from staying afloat causing the vessel to capsize. Vessels that are broken from the moorings or navigating out of the harbour can be caught in turbulent, currents and eddies, some uncontrollably spin. Vessels can be entrained as debris in the flow, colliding with other debris and potentially destroying structures in their path. Even smaller boats as debris can cause significant damage to light steel and timber structures. Vessels can be carried inland causing fuel and oil spillages (Okal et al., 2002; Okal et al., 2006; PIANC, 2010; Chock et al., 2013; Wilson et al., 2013; Borrero et al., 2015; Horspool & Fraser, 2016).

- Shipping containers:
    - Containers subject to buoyant and hydrodynamic forces can be moved from their original position, or stacks, and carried by tsunami and entrained in the flow causing further damage in the port as observed during the GEJ and 2015 Illapel tsunamis (Horspool & Fraser, 2016). Containers can be damaged through debris strikes; contents inside containers could then be susceptible to water damage, be dislodged and may move inside the container, if these contents are dangerous goods this could cause fire, explosion or pollution (PIANC 2010; Chock et al., 2013; Borrero et al., 2015).
- Wharf Services:
    - Other infrastructure that services ports including electricity, communications, water pipes and fuel lines are susceptible to debris strikes, sedimentation, buoyant and hydrodynamic forces (Horspool & Fraser, 2016). Turnbull & Hughes (2017) mention flooding of generators and clogging of pumps with sand. Damage to these services also serves potential to cause cascading hazards such as fire.
- Harbour Navigation:
    - Tsunami can have high velocity flow and often create eddies (circular currents) in harbours and ports where narrow entrances and shallow channels constrict tsunami flow (Wilson et al., 2013). Tsuanmis alter harbour bathymetry through debris deposition, scour and sediment accumulation (Power, 2013a).

2.1.2.3.2 Energy

2.1.2.3.2.1 Tsunami Impacts on Electricity Infrastructure

During the 2011 GEJ tsunami, the electricity network was majorly affected due to damage at substations along the coast. Disruption was also caused by damage to the distribution network (power poles, lines and transformers) from hydrodynamic forces, debris strikes and scour (Scawthorn & Porter, 2011). During the 2004 Indian Ocean Tsunami, tsunami depths of 3-10 m caused failure of tens of kilometers of overhead line due to felled or leaning power poles, as well as inundated transformers which needed to be replaced due to salt water intrusion (Tang et al., 2006). Flow depths of 1-5 m, lateral forces and debris strikes damaged power poles and overhead lines during the 2015 Illapel tsunami.

Observations of tsunami impacts on buried cables are sparse, but the limited evidence collected shows that buried cables are less vulnerable than overhead lines and that damage can be expected to be localised at exchange points and buildings (Horspool & Fraser, 2016).

Observations have shown disruption to the electricity network is more likely to occur if:

- Substations are in low-elevation areas proximal to the coast (Scawthorn & Porter, 2011).
- Transformers are attached to power poles are at a low elevation (bottom or mid pole) (Tang et al., 2006).
- Power poles are set in soil and the soil is susceptible to erosion (Horspool & Fraser, 2016).
- Power poles have a base plate, making then susceptible to shear and complete wash away (poles may be less vulnerable if set in a foundation) (Horspool & Fraser, 2016).
- The tsunami height reaches the height of the lines, causing them to sever and wash away.
- Scour occurs around buried cables and the cable housing integrity or water tightness is compromised (leading to salt-water infiltration of the cable), or if cables are severed at connection points (such as across a bridge or entry points to buildings) (Tang et al., 2006).

Past tsunami events have also revealed an issue regarding back-up generators which are often located in building basements or on ground floors and vulnerable to inundation (Horspool and Fraser, 2016).

Impacts on the electricity network also increases fire risk (Power, 2013a).

2.1.2.3.2.2 Tsunami Impacts on Fuel Infrastructure

Tsunamis can damage fuel tanks, pipelines, pump facilities and associated connection components. Observations from past events have shown that fuel tanks (above-ground) are susceptible to:

- Damage caused by buoyant forces (causing tanks to float or slide) (Figure 2.5).
- Debris impacts (on bowsers, connections and tank walls) (Figure 2.5).
- Hydrostatic forces (which can cause buckling near the base of the tank).
- As well as scour and liquefaction of foundations (TCLEE, 2010; Hatayama, 2014; Horspool & Fraser 2016).

Observations have revealed little to no damage occurs to above-ground fuel tanks during tsunami flows < 1 m, but tanks are always damaged during tsunami flows of > 7 m (Hatayama, 2014). "It appears from the observational data that small tanks and those that are less than half full are more susceptible to sliding and floatation than larger capacity and full tanks, "(Horspool and Fraser, 2016, p.54).

Underground fuel tanks and fuel pipe networks have been observed to be damaged when subjected to tsunami depths 2 m and greater (Horspool and Fraser, 2016).

Fuel stations are also susceptible to damage. During the 2015 Illapel tsunami, tsunami depths of 1- 2 m damaged fuel pumps and backup generators at a fuel station. The underground tanks were not damaged but the fuel station was not operational until new pumps were installed and the station accessed electricity supply (Horspool & Fraser, 2016).

Tsunami impacts on fuel infrastructure can lead to cascading hazards including fuel spills into marine environments and fire. Tsunami flows and currents can distribute combustible liquids around harbours and as the tsunami inundates land, also spreading fire risk. Fires exacerbated damage tsunami impacts during the 2004 Indian Ocean tsunami in Banda Aceh (Borrero, 2005), and during the 2011 GEJ tsunami (EEFIT, 2011).

Figure 2.5. Tsunami damage to fuel tanks. Left: Debris (a house roof) impacts to a large tank following the 2017 Greenland tsunami (Newshub, 2017). Right: Fuel tank has been carried from its source and has also been impacted by debris strikes (see dents) during the 2011 GEJ Tsunami, retrieved from Flack & Sudima, 2011.

2.1.2.3.3 Telecommunications Infrastructure

Observations from past events have indicated the telecommunication networks are affected by:

- Damage to landline cable (salt water infiltration or severing) through scour, debris impacts or by hydrodynamic forces (Horspool & Fraser, 2016), the most vulnerable landline is that across bridges.
- Damage to communication cables at sites where they entered buildings (areas susceptible to high flow velocities and scour).
- Damage to exchange centers (Kwasinski, 2013).
- Damage to stand-alone utility poles/towers, damaged by scour at the base as well as damage to electrical components. Stand-alone communication utility poles were completely destroyed

when subjected to flow depths > 2 m (due to debris strikes) in the 2011 GEJ tsunami (Kwasinski, 2013).

- Loss of electricity to repeater sites both in and out of inundated areas (Kwasinski, 2013).

In Japan, the majority of communication services could not be restored until the electricity network was restored. Cell sites are also vulnerable to tsunami impact (Horspool & Fraser, 2016), but were not included in this lit review as there are none on the Chatham Islands. Radio towers have also been damaged in tsunami events (Horspool & Fraser, 2016). However, radio towers are located on high elevations on the Chatham Islands thus literature review is negligible for this study.

2.1.2.3.4 Water Infrastructure

Water infrastructure vulnerable to tsunami impact includes tanks, pipes and treatment facilities. Observations from recent tsunami events have revealed that:

- Pipe networks are most vulnerable when above ground, including where pipes cross waterways (attached to a bridge or in isolation). During the 2015 Illapel tsunami, a main, steel water pipe was severed at a bridge located at the coast which was subjected to 2 – 3 m (Horspool & Fraser, 2016).
- Pipe networks are also tend to be damaged at entry points into homes, including damage to household water meters as well as at facility buildings and pipe intake and outflow sites. (Takada, Kuwata, & Pinta, 2010).
- Flexible pipes (made of HDPE plastic and steel) performed the best (Horspool and Fraser, 2016).
- If material around buried pipes is severely scoured the pipe may float and disrupt gravity-fed fluids (Horspool & Fraser, 2016).
- Water facilities can be impacted by low inundation depths (i.e., < 2 m), due to submersion of electrical and mechanical equipment.
- “In general, buried pipes for potable water supply performed well in most recent tsunami. Often scouring exposed pipes but there was often little damage even when the pipe was covered with heavy debris,” (Horspool and Fraser, 2016, p. 35). Horspool and Fraser (2016) suspect at polyethylene water tanks, (common in New Zealand), would float at low flow depths (lower than concrete, which can float at few meters), depending on how full the tank is.
- Contamination of potable water can occur with even small amounts of infiltration of seawater.

2.1.2.4 Tsunami in New Zealand

2.1.2.4.1 Sources of Tsunami for New Zealand & Tsunami History

The entire New Zealand coastline is exposed to tsunami from local, regional (near-field) and distal (far-field) sources.

- Local sources lie within one hour's tsunami travel distance; official warnings are not issued for local source tsunami due to the lack of time available to disseminate a message. Therefore, it is advised that if people feel a long (lasting a minute or more), or strong (hard to stand up) earthquake, see a sudden rise or fall in sea level and/or hear loud and unusual noises from the sea, they should head inland or to higher ground immediately (Power, 2013a; MCDEM, n.d).
- Regional tsunami sources lie between one and three hour's tsunami travel distance away. An official warning may or may not be issued for a regional source tsunami, thus the same advice applies as for local sources. Local and regional sources (Figure 2.6), vary for locations around New Zealand; a fault line classified as a local source for Gisborne would not be considered a local source for Fiordland due to the different travel time (Power, 2013a). Regional sources for A-NZ include the Puysegur trench and the Tonga-Kermadec trench (Power, 2013a).
- Distal sources (Figure 2.7) are located more than three hours' tsunami travel distance away (Power, 2013a). The Pacific Rim subduction zone generates most distal source tsunami that impact New Zealand. The most active distal source is the Peruvian Subduction Zone (South and Central America). Other distal sources include Kamchatka-Kuril-Japan, Alaska-Aleutian, Solomon Islands and Tonga-Kermadec subduction zones (Power, 2013a). An official warning would be issued for these tsunami.

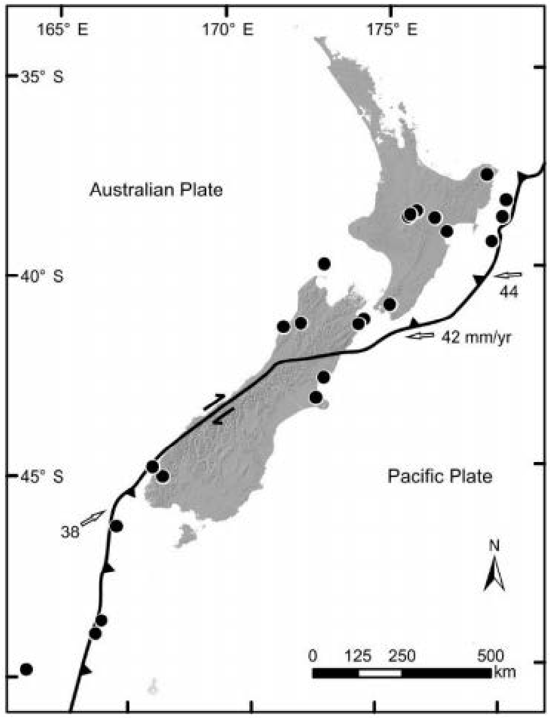

Figure 2.6. Historic local tsunami sources, represented by black dots; note tsunami occur in lakes as well as in the sea. Adapted from data obtained from the New Zealand Tsunami Database (GNS Science, 2014) from Scheele (2016).

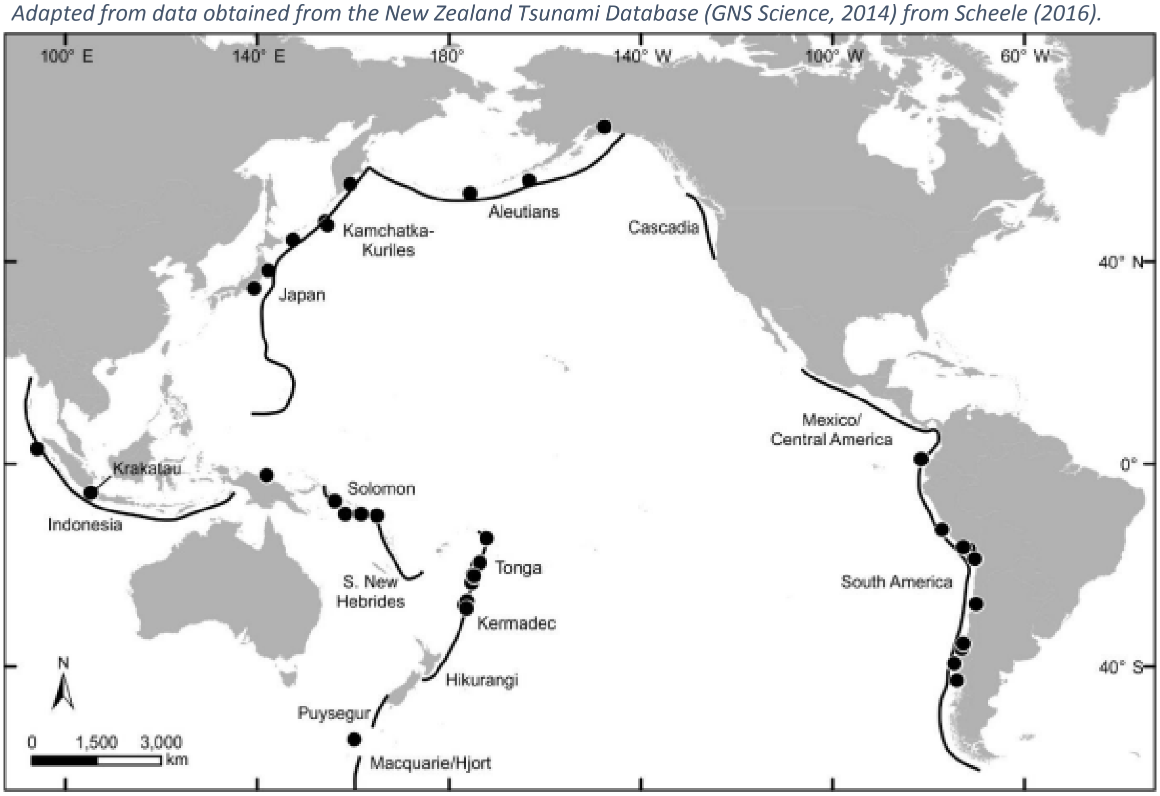

Figure 2.7. Regional and distal tsunami source areas (all generated by earthquakes with the exception of Krakatau volcanic eruption) marked by black dots, representing tsunami that have impacted New Zealand between 1835 and 2011. Plate boundaries (black lines) are also shown in this figure representing potential future tsunami event sources. Adapted from data obtained from GNS Science, 2014 by Scheele (2016).

New Zealand has a long history of tsunami, a detailed record of historical tsunami impacts and access to pre-written knowledge of tsunami in oral histories. Destructive events impacted Māori communities during the 12th - 17th centuries and records show that at least 80 tsunami events have been experienced between 1835 and 2011 (Power, 2013; McFadgen, 2007; Table 2.1). Large offshore earthquakes on subduction zones are the primary source of destructive tsunami events in New Zealand (Power, 2013a; GNS Science, 2014). However, historic and pre-historic tsunami that have impacted New Zealand have also been caused by landslides (coastal/lakeslide or submarine) and volcanism (Krakatau in 1883) (De Lange and Healy, 1986; GNS Science, 2014).

Table 2.1. Tsunami that had a run up of greater than 1 m (1831-2012). Retrieved from King (2015, p.29).

Date of tsunami arrival	Time (NZST)	Run-up location	Maximum run-up (m above MSL)	Tsunami source region	Date of source event	Time (NZST)	Magnitude (Mw)
1831–1834	Unknown	Poverty Bay, Gisborne	3.0	Gisborne, A–NZ	1831–1834	Unknown	~6.0–7.0
February–July 1839	~12:30	Waikawa, Southland	1.5	Local?	February–July 1839	Unknown	n/a
August 1840	Unknown	Hicks Bay/Te Araroa, Gisborne	>1.0	Distant?	August 1840	Unknown	n/a
23 January 1855	21:00	Palliser Bay, Wairarapa	12.5	Wairarapa, A–NZ	23 January 1855	~21:00	8.2–8.3
15 August 1868	00:15	Owenga, Chatham Islands	>10.0	Peru–Chile, South America	14 August 1868	~09:00	8.8–9.5
11 May 1877	08:00	Little Akaloa Bay, Canterbury	3.6	Arica, Chile	10 May 1877	12:29	8.8
8 September 1880	~22:00	Poverty Bay, Gisborne	1.5–2.0?	Poverty Bay, Gisborne	8 September 1880	22:00	~7.0
29 June 1881	11:30	Pigeon Bay, Canterbury	3.0	Local?	29 June 1881	~11:30	n/a
28–29 August 1883	Afternoon	Whangara, Gisborne	1.0–2.0?	Krakatoa, Indonesia	27 August 1883	1429	Eruption
December 1886	Unknown	Jackson Bay, West Coast	1.8	Jackson Bay, West Coast	December 1886	Unknown	Landslide
10 July 1895	18:00	Pigeon Bay, Canterbury	3.0–5.0?	Pigeon Bay, Canterbury	10 July 1895	18:00	Landslide
20 March 1910	Morning	Little Waihi – Taupo, Waikato	1.0–1.5?	Little Waihi – Taupo, Waikato	20 March 1910	Morning	Landslide
22 February 1913	~12:36	Cape Foulwind, West Coast	1.0–2.0	Cape Foulwind, West Coast	22 February 1913	~12:36	6.8
19 July 1924	19:15?	Kaingaroa/Owenga, Chatham Islands	6.0	Unknown	19 July 1924	Unknown	n/a
16 June 1929	10.17	Karamea, West Coast	2.5	Karamea – West Coast, A–NZ	16 June 1929	10:17	Earthquake Landslide
3 February 1931	Unknown	Waikare River, Hawkes Bay	≥15.0	Hawkes Bay, A–NZ	2 February 1931	20:17	7.4–7.6
16 September 1932	Unknown	Wairoa, Hawkes Bay	3.0	Wairoa – Hawkes Bay, A–NZ	16 September 1932	01:25	6.9
2 April 1946	20:30	Mangonui and Tutukaka, Northland	1.2	Unimak Island – Alaska, USA	2 April 1946	00:28	8.1
26 March 1947	08:40	Pouawa Beach and Turihaua Point, Gisborne	~10.0	Poverty Bay, Gisborne	26 March 1947	08:32	7.0–7.1
17 May 1947	~19.30	Waihau Beach, Gisborne	6.0	Tolaga Bay, Gisborne	17 May 1947	19.06	6.9–7.1
23 May 1960	23.24	Napier, East Coast	4.5	Chile	23 May 1960	07:11	9.4–9.6
29 March 1964	20.00	Picton, Marlborough	1.5	Alaska, USA	28 March 1964	15:36	9.2
20 May 1987	Unknown	Deep Cove, Fiordland	3.0	Deep Cove, Fiordland	20 May 1987	Unknown	Landslide
22 August 2003	~00:12	Charles Sound, Fiordland	5.0	Charles Sound,Fiordland	22 August 2003	00:12	Earthquake Landslide
27 December 2004	07.05	Timaru, Otago	1.0	Sumatra, Indonesia	26 December 2004	13:01	2004

2.1.2.5 Indigenous Knowledge of Tsunami

Indigenous[1] knowledge (IK) of tsunami hazard and history is part of the knowledge complex of many indigenous peoples (Vitaliano, 1973; Heaton & Snavely, 1985; Ludwin et al., 2005; Becker et al., 2008; Arunotai, 2008; McAdoo, Moore, & Baumwoll, 2009; Walshe & Nunn, 2012; among others). Indigenous populations have learned through centuries of experience how to adapt to environmental change and adjust their cultures and livelihoods to reduce the impacts of natural hazards (Mercer et al., 2007). The potential of IK to inform more effective DRR initiatives has also recently been considered (e.g. Lewis, 1989; Cronin et al., 2004; Wisner, 2004, Ellemor, 2005; Mercer et al., 2007; UNISDR, 2015-2030). The Sendai Framework states: "indigenous peoples, through their experience and traditional knowledge, provide an important contribution to the development and implementation of plans and mechanisms" (UNISDR, 2015-2030, P.23). It is this knowledge that needs to be drawn upon to help understand hazard frequency and magnitude and to mitigate impacts for, with, and by rural indigenous communities (Mercer et al., 2007).

In Aotearoa-New Zealand (A-NZ) Māori have developed a detailed knowledge surrounding natural hazards, including tsunami (Lowe, Newnham, & McCraw, 2002; King, Goff, & Skipper, 2007; McFadgen, 2007; Pardo, Wilson, Procter, Lattughi, & Black, 2015). This knowledge of the environment is part of the broader knowledge-practice-belief complex of Mātauranga Māori (King & Goff, 2010; King et al., 2018). King, Skipper & Tawhai (2008) explain that a dominant challenge for early Māori was to adapt to an environment that was different to their former Polynesian homes. To survive, Māori learned to understand, monitor, plan for, and adapt to natural hazards. Some of the empirical strands of knowledge included (and still include) observations of past natural hazard events. These have been passed down the generations through oral history and traditions that record past events, place names that record areas of high risk or fatality, and knowledge of environmental indicators to assess potential danger (King et al., 2007; King & Goff, 2010).

Dominey-Howes and Goff (2013) suggest that investigating traditional knowledge of historic and pre-historic tsunami should be a priority for bridging existing tsunami hazard knowledge gaps in A-NZ. While

[1] The term 'indigenous' encompasses many diverse cultures, communities, language groups and nations, used in contexts such as Australia and North America (Smith, 1999). In Aotearoa-New Zealand (A-NZ), the terms 'Tangata Whenua' (people of the land) or 'Māori' are more frequently used than the widely applied term 'indigenous'. Origin and tribal terms including waka (canoes that ancestors arrived on), Iwi (tribe), hapū (sub-tribe) and whānau (family units) are then used to identify different groups.

there is geological and oral history of many historical and pre-historic tsunami in A-NZ, the current documented history of tsunami and their impacts is short. Documented accounts of tsunami events in A-NZ only extend back to the 1800s when written language was introduced by Europeans (GNS, 2014). By way of comparison, Japan has a written record of tsunami extending some 1300 years (Cartwright & Nakamura, 2008). Information on past tsunami events, their sources, magnitudes, inundation extents and impacts is valuable for understanding what may happen in the future and can help improve collective understanding about low-frequency high-magnitude events, of which modern A-NZ has little experience (King 2015; Barberopoulou & Scheele, 2016; Quentel, Loevenbruck, Hébert & Allgeyer, 2013). By utilising both scientific and decolonising research frameworks, we can benefit from differences in knowledge with the potential to learn more about our collective natural hazards histories and the distinct requirements facing different populations in different places (Pardo et al., 2015). Many commentators have argued that disaster risk reduction strategies would be more effective if they involved a multidisciplinary, locally integrated approach implemented by local and indigenous agencies (Lewis, 1982; Mercer et al., 2007; King, 2007; Gaillard & Mercer, 2013 among others).

There have been several contributions to gathering and documenting Māori knowledge of natural hazards in A-NZ (Skinner, 1965; McCraw, 1990; Goff et al., 2003, 2012; Grattan & Torrence, 2003; Mitchell & Mitchell, 2004; Parnell, 2004; King et al., 2007, 2011, 2017, 2018; McFadgen, 2007; McFadgen and Goff, 2007; King, Skipper & Tawhai, 2008; Webber, 2008; Pearce and Pearce, 2010; King & Goff, 2010; Jardine-Coom, 2010; Pardo et al., 2015). There have also been contributions investigating Māori resilience to natural disasters including the role of Māori culture and cultural assets in fostering effective preparedness, response and recovery (Hudson et al., 2007; Kenney & Phibbs, 2015; Kenney, Phibbs, Paton, Reid & Johnston, 2015; King et al., 2011; 2012; 2013; Lambert, 2014; Lambert, 2015; Phibbs, Kenney & Solomon, 2015).

2.1.2.5.1 Indigenous Research Methodologies

Knowledge is highly valued and sacred in Māori culture, traditionally gate-kept by Tohunga (experts in a specified field) and developed or transferred through whāre wānanga or specialised schools (Te Awekotuku, 1991). Certain knowledge was tightly regulated, restricted to people who had been trained to receive the knowledge, who understood the responsibility of safeguarding and transferring the knowledge to the next generation. These specialists were often designated at birth (Te Awekotuku, 1991).

Māori histories are built from multiple layers of knowledge and experience and are concerned with genealogy. These histories hold purpose, to record discrete and repeated historical events (and the cultural meanings for these events) as well as to validate family claims to lands, authority and knowledge (Binney, 1987; King et al., 2018). The challenge for researchers is to understand the Mātauranga Māori cultural context behind historical narratives; i.e. that Māori knowledge systems contain more than alternative sources or alternative perspectives but have their own purposes. Researchers should understand and acknowledge these purposes and be responsible to them, so as to not remove the histories from their cultural context (Binney, 1987; King et al., 2018).

Māori academics have advocated and sought for Māori-centered approaches to enquiry through appropriate methodologies that include Mātauranga Māori and that address issues such as cultural and intellectual property rights (Smith, 1999; Davidson & Tolich, 2003; King et al., 2018). Māori-centered research is for Māori, with Māori and by Māori, whereby Māori have conceptual, methodological and interpretive control (Smith, 1999).

Research that involves Māori knowledge, alike all social research, comes with ethical responsibility. Indigenous populations, including Māori, have been mistreated throughout western colonisation and by researchers in the past; in short, Māori knowledge was taken, misinterpreted and misused. As a result, some of Māori history, written by Pākehā, is wrong and has caused significant strife (Smith, 1999). Much of the research conducted on Māori has also proved to be of little benefit to Māori (Davidson & Tolich, 2003). Thus, it comes as no surprise that some Iwi, hapū and whānau are suspicious, distrusting and resistant to sharing their knowledge with people outside their trusted and respected communities (King et al., 2008; Davidson & Tolich, 2003).

Indigenous methodologies attempt to prevent the wrong-doings mentioned above from being repeated. "Indigenous methodologies tend to approach cultural protocols, values and behaviors as an integral part of methodology. They are 'factors' to be built in to research explicitly, to be thought about reflexively, to be declared openly as part of the research design, to be discussed as a part of the final results of a study and to be disseminated back to the people in culturally appropriate ways and in a language that can be understood," (Smith, 1999, p.15). This includes being respectful and making sure the knowledge is shared with the people who have helped create it, not just publishing it in academic articles. 'Sharing knowledge' assumes two-way dialogue and feedback (Smith, 1999).

Kaupapa Māori Research is a counter-colonial research methodology specific to A-NZ (Smith, 1999). An important aspect of Kaupapa Māori Research is that it seeks to understand and represent Māori, as Māori. This can include structural analysis of the historical, political, social and economic determinants (enablers and barriers) of Māori well-being. Kaupapa Māori research dictates that Māori tikanga[2] and processes are followed throughout the research, from inception to the dissemination of results to the ongoing relationship formed between the researcher(s) and the research participant(s). We engage with our community and involve them in the research (Katoa Ltd, n.d). Kaupapa Māori research principles to abide by when undertaking research concerning Māori include;

- Aroha ki te tangata (a respect for people, this is part of the Māori cultural principle of manaakitanga[3])
- Kanohi Kitea (the seen face - present yourself to people face to face)
- Titiro, whakarongo … kōrero (look, listen… then speak).
- Manaaki ki te tangata (share and host people, be generous, also part of manaakitanga).
- Kia tūpato (be cautious).
- Kaua e takahia te mana o te tangata (do not trample over the mana of people, also part of manaakitanga).
- Kaua e māhaki (don't flaunt your knowledge) (Smith, 1999, p.15).

These principles (that should be used to guide behavior and methods) reflect Māori cultural values and can be used to characterise a good quality person suitable and worthy to carry out the research (Smith, 1999). Other Kaupapa Māori principles to abide by when undertaking research concerning Māori include whānau, whanaungatanga and kaitiakitanga (Māori terms and definitions are provided in Appendix A). Whānau is family, and families are the "core units of cultural capital" (Kenney, Phibbs, Paton, Reid & Johnston, 2015, p.3). Whanaungatanga is relationships, or kinship with extended family, friends and nature (connections to mountains, rivers, forests, lakes). These relationships are highly valued and are fostered through shared experiences over time and whakapapa (genealogy) (Reed & Kāretu,

[2] Tikanga involves physical and cultural practices and appropriate action which are guided by principles, values and spirituality. Wāhi tapu is a part of tikanga; it involves classing a place as tapu (sacred) and implements long-term restrictions on access or use of a place. Areas of Wāhi tapu may be dangerous or have suffered catastrophic events in the past (Mead, 2013). 'Kanohi kitea' or the 'seen face' is also part of tikanga, it conveys the need to show your face to, or be seen by, the community during important cultural events, and in times of need, to develop your ongoing membership with the community to develop and maintain credibility and trust (Smith, 1999). Credibility and trust are also concepts that appear time after time in literature associated with community engagement and participation in DRR (Twigg, 2004).

[3] Manaakitanga is respect, support and outreaching hospitality to build the strength of others (Kenney et al., 2015).

1985). “Whakawhanaungatanga is the process of building and maintaining relationships, including the operationalisation of intra and extra-tribal relationships to mobilise resources and activate social support networks” (Kenney et al., 2015, p.11). Kaitiakitanga involves development of protection and guardianship through social obligation to create a safe environment achieved by belief in self-sufficiency and the idea that the community, as a whole, will pull through (Kenney et al., 2015).

Māori have obtained knowledge of natural hazards through direct experience. These experiences, lessons learned and cultural changes have been passed down through successive generations, orally, through whānau and whakapapa, as a part of a wider understanding of the natural environment and connections with the spiritual world. This uniquely Māori way of understanding the environment is known as Mātauranga Māori. Through passing knowledge down through successive generations, lessons learnt were incorporated into traditional and modern practices of hunting and gathering, agriculture, medicine, education and conservation (King et al., 2008). Māori knowledge of natural hazards exists in various forms and expressions which differ based on Iwi, hapū and whānau, local geography, traditions and practices (King et al., 2008).

Events can be recorded through pūrākau (true stories), pakiwaitara (fairytale stories), mōteatea (laments), pepeha (quotations), whakatauki (proverbs) and waiata (songs) (King et al., 2007). King et al. (2007) found tsunami in oral history are often referred to as taniwha (monsters), which are affiliated with wrong-doings, resulting in punishment and are associated with death and destruction. Tsunami are also recorded in place names (King et al., 2007; King & Goff, 2010).

Forms of Māori knowledge can be described as oral history or oral tradition and are conveyed through kōrero (conversation). Oral history usually refers to interviewing a participant about a first-hand experience (Cruikshank, 1994). Recording oral tradition involves material retained or passed down from the past; this material can be stored in stories, or stored within genealogies (of the landscape, weavings, carvings, names of people and adzes) (Cruikshank, 1994; Smith, 1999).

2.1.2.6 Tsunami in the Chatham Islands

2.1.2.6.1 Tsunami Sources and History

The Chatham Islands are exposed on all sides to impact from local, regional and distal-source tsunami (Nichol et al., 2010; Figure 2.8). Several historical tsunami have inundated the Chatham Islands causing destruction of assets and in one case, fatalities. Known inundation events occurred in 1604 AD, 1868 AD, 1877 AD, 1924 AD, 1946 AD 1947 AD and 1960 AD (Goff et al., 2010; De Lange & McSaveney, 2006; Johnston et al., unpublished). These tsunami were generated from a range of sources shown in Figure 3. However, the Peruvian Subduction Zone, offshore of South and Central America, is the most frequent source of tsunami for the Chatham Islands (occurring in 1604, 1868, 1877 and 1960) and has caused the greatest recorded impacts (Power & GNS Science, 2014; Goff et al., 2010; Johnston et al., unpublished). While there is no specific evidence of tsunami events pre-1604 AD, it is likely that many distant, trans-South Pacific source tsunami would have inundated the Chatham Islands (Goff et al., 2010).

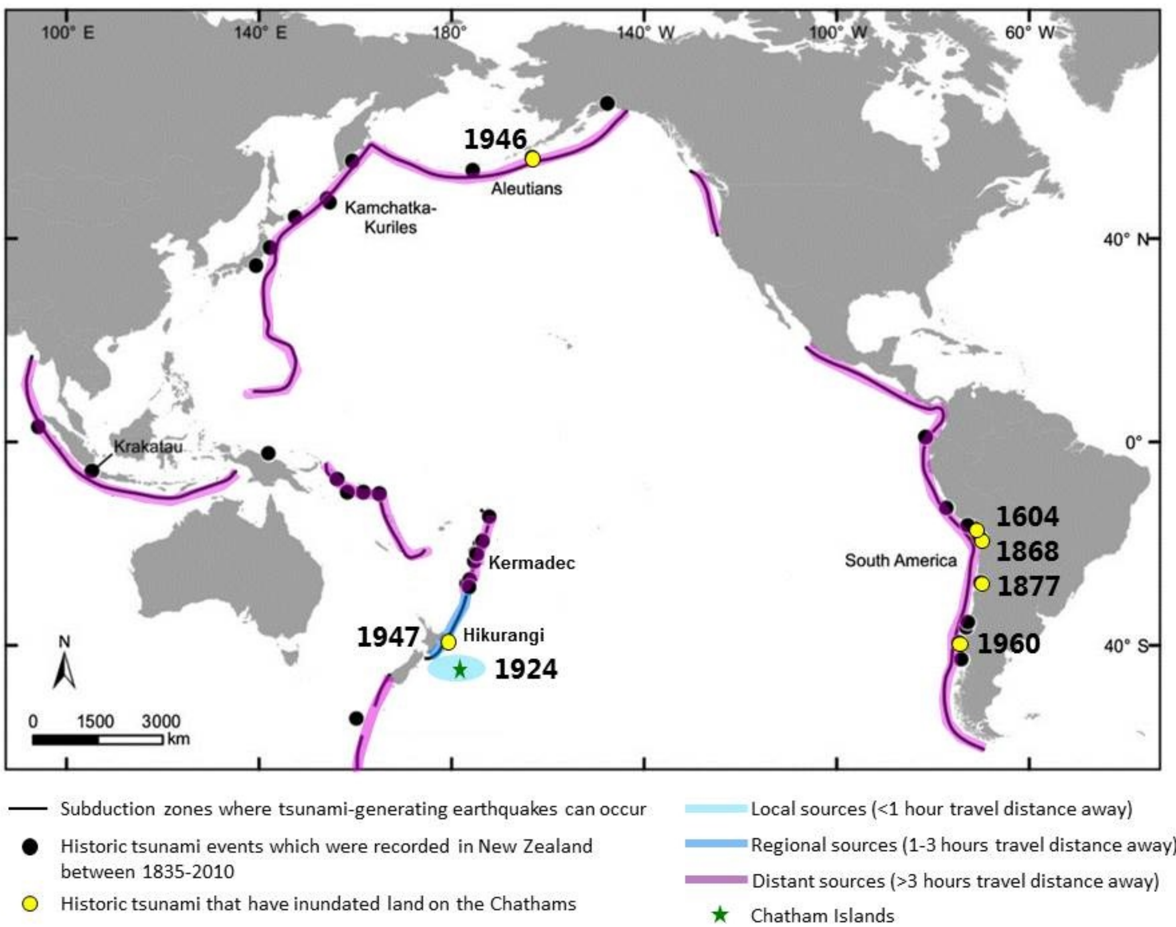

Figure 2.8. Tsunami sources for the Chatham Islands and localities of historical events. The source location of the 1924 event is unknown, it may have been generated by a local submarine landslide or earthquake (GeoNet, n.d.-a). Figure adapted from Downes et al., (2017). Local, regional and distant source boundaries defined by information from Berryman (2005), Hayes & Furlong (2010), Power & Gale (2011), Power (2013a).

Other historical sources include the Aleutian Islands, Gisborne (A-NZ) and an unidentified local source (Thomas, 2017). Probabilistic analysis of tsunami hazard for the Chatham Islands (1.3.3.2.3) indicates that Peru, Central Chile, the Kermadec Trench (A-NZ), Hikurangi Subduction Zone (A-NZ), Northern Chile, the Kuril Kamchatka Trench (Japan), and the Aleutian Trench (Alaska) are potential tsunami sources for the Chatham Islands (Power, 2013b).

2.1.3 Tsunami Impact Assessment Process

The normal day-to-day operation of society, and of the economy, is dependent on the functioning of critical (lifeline) infrastructure assets[4] to provide essential services[5] such as water, communications, electricity, transport and sewage (Fotouhi, Moryadee & Miller-Hooks, 2017; Williams, 2016). Natural hazards, including tsunami, can damage critical infrastructure such as bridges, ports, powerpoles, underground cables and cause disruptions, affecting the level-of-service (LoS) provided to users (Blake et al., 2017). The restoration of these services is vital for response, restoring functionality and recovery as widespread loss of services over long periods of time can induce serious psycho-social impacts, economic loss, and environmental damage and subsequent difficulties for emergency response agencies (Giovinazzi et al., 2017; Deshmukh, Oh and Hastak, 2013; Horspool & Fraser, 2016). Thus Blake et al. (2017) state that the loss of critical infrastructure functionality (reduction in LoS) "may be equally, if not more important to consider than direct damage in many situations" (p.93).

A core component of this research project is an *ex ante* tsunami impact assessment of infrastructure to provide an impact scenario which the community can use to evaluate their capacity to respond to such impacts and to derive impact reduction options. *Ex ante* impact assessments are carried out prior to an event and involve a hazard metric, determining the assets exposed to the hazard and assessing their vulnerability in order to evaluate potential impacts which can then be used to evaluate impact reduction options (Power, 2013; Scheele, 2016; Williams; 2016; Schneider, Hoffmann & Reicherter, 2016; Figure 6). Impact assessments, which integrate hazard, asset exposure and asset vulnerability have only recently attracted widespread interest following the 2004 Indian Ocean Tsunami. This is due to the severity of urban impacts experienced during this and subsequent events and to "a lack of empirical measurements of hazard intensity or building damage before this time" (Scheele, 2016, p.18; Power 2013a, Papadopoulos & Imamura, 2001; Synolakis and Bernard, 2006).

As Scheele (2016) and Williams (2016) indicate, there is no standardised methodology or framework to outline how to conduct *ex ante* tsunami impact assessments. Previous assessments have been used to model and evaluate tsunami impacts on buildings/habitability, infrastructure/loss of services, potential economic loss, and loss of life. These assessments use a variety of probabilistic, deterministic (scenario-based), qualitative, semi-quantitative and quantitative approaches, the majority of which incorporate

[4] Critical infrastructure is the systems, assets, facilities and networks that provide essential services (Critical Five, 2014). Critical infrastructure assets include power poles, transformers, bridges and other network components that allow the infrastructure system to operate.
[5] Essential services are provided by operational critical infrastructure assets. Services include running water, electricity, communications, sewage and transportation networks.

the use of a Geographic Information System (GIS) and each have their pros and cons as discussed in 1.2.4.4.2 (Sambah & Miura, 2014; NZIER, 2015; Scheele, 2016; Williams; 2016; Schneider, Hoffmann & Reicherter, 2016). The present impact assessment is scenario-based, utilising semi-quantitative data, and follows the risk assessment process described in 1.3.1.3 to combine hazard and exposure information to evaluate vulnerability and determine impacts as shown in Figure 2.9.

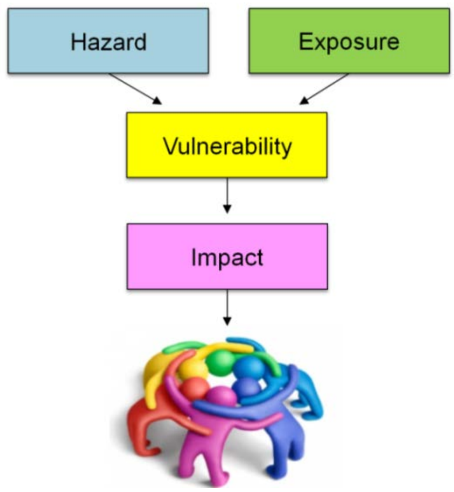

Figure 2.9. Impact assessment process. Hazard and exposure information are combined to evaluate vulnerability and determine potential impacts. Once impacts are evaluated, stakeholders are able to discuss impact reduction options. Adapted from Scheele (2016).

2.1.3.1 Hazard Metric

As mentioned previously, impact assessments require a hazard component in order to assess exposure and vulnerability to determine potential impacts. Tsunami hazard characteristics such as inundation depth, inundation duration, flow velocity and ponding are applied to exposed assets located within the hazard footprint to quantify impact (Power, 2013a; RiskScape, 2017). Numerical tsunami models are used to quantify these characteristics and can be deterministic (either based on a past event or possible future scenario) or probabilistic (hazard characteristics are associated with a frequency of occurrence). The quality of these models is dependent on the input data such as the resolution of local bathymetry and topography. Available tsunami hazard models for the Chatham Islands are listed in 1.3.3.2.

2.1.3.2 Asset Exposure

Exposure is understood as the quantity of assets within the spatial extent of a hazard, in this case, the amount of infrastructure within the tsunami inundation limits; a spatial-temporal (space-time) relationship exists between the hazard and the assets exposed (Power, 2013a). Assessing exposure also requires a good understanding of an infrastructure asset's location and attributes, interactions with other assets (dependencies and interdependencies), and criticality (importance of assets) (Strunz et al., 2011; Power, 2013a).

2.1.3.2.1 Asset attributes

Assets have attributes or characteristics that determine how well they may withstand a hazard and are relevant for calculating impact (Tarbotton et al., 2015; Williams, 2016; Scheele, 2016). Building and infrastructure attributes include construction material, age, height above ground level (floor height) and other relevant attributes for input into vulnerability models (RiskScape, 2017). Asset attribute data for Chatham Island infrastructure do not exist. However, relevant and applicable attribute modules to guide attribute data collection for New Zealand infrastructure are provided by RiskScape, a loss modelling tool created by NIWA and GNS Science to support evidence-based risk assessments for natural hazards (RiskScape, 2017).

2.1.3.2.2 Infrastructure Interactions

Understanding infrastructure interactions allows identification of assets that are not directly exposed to tsunami impacts but may be indirectly affected. Operation of an infrastructure network often depends on interactions within or across different networks (e.g. the potable water network relies on electricity to pump water from wells to users) (Figure 2.10). These interactions can be described as either one-way (dependencies) or two-way (interdependencies) (Fotouhi et al., 2017). Due to dependencies and interdependencies, when an infrastructure asset is impacted, it may cause cascading failures (one failure leading to another) of dependent assets, within the same network and/or across networks (Sword-Daniels et al., 2015; Fotouhi et al., 2017). Thus, assets that are not directly impacted by a hazard can still be damaged or lose function (e.g. a water pump in a safe zone may lose function if power poles in the hazard path are destroyed). Thus, exposure of infrastructure assets can extend beyond the hazard footprint.

To consider all possible infrastructure interdependencies to better understand exposure would require substantial modelling, which is beyond the scope of this thesis. Identifying infrastructure hotspots and pinchpoints through scenario-based approaches is an alternative method used to determine potential cascading failures (Sword-Daniels et al., 2015; Hughes & Healy, 2014).

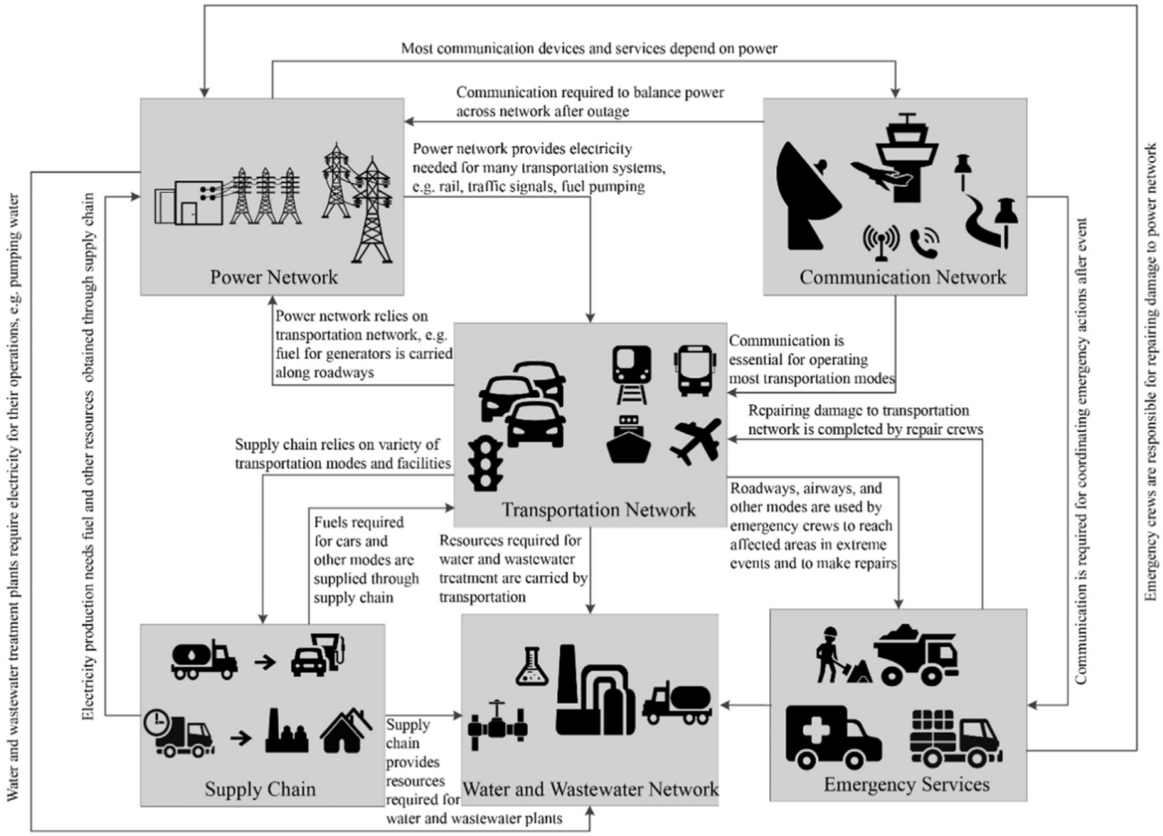

Figure 2.10. Infrastructure interactions and dependencies. Retrieved from Fotouhi, Moryadee & Miller-Hooks (2017, p.82).

2.1.3.2.2.1 Hotspots and Pinchpoints

Hotspots and pinchpoints are a way of pinpointing interaction sites that could initiate cascading failure. Hotspots are places where a number of infrastructure assets from different networks are co-located and interdependent (Ladbrook et al., 2013; National Infrastructure Unit, 2014; Roberts, n.d; Roberts 2015; Sims, n.d). Pinchpoints represent single points of failure within an infrastructure network i.e. critical assets or utilities within a network where a satisfactory alternative route does not currently exist (Ladbrook et al., 2013; National Infrastructure Unit, 2014; Roberts, n.d; Roberts 2015; Sims, n.d). However, “It is important to note that the identification of a pinchpoint or hotspot does not necessarily imply that there is a weakness or vulnerability but that these areas deserve particular attention in terms of on-going operations and future investment” (National Infrastructure Unit, 2014, p.10). Hotspots and pinchpoints can be located through expert elicitation and judgment and/or kernel density estimation which is a GIS tool based on statistics that evaluates intersections in infrastructure networks to locate hotspots (Roberts, n.d; Roberts, 2015; Thacker et al., 2017).

2.1.3.2.2.2 Infrastructure Criticality

Infrastructure criticality is an important characteristic that should be considered before assessing vulnerability and calculating impacts (Fekete, Tzavella & Baumhauer, 2017). It involves considering the consequences of service failure if infrastructure components (assets/lines/facilities) malfunction, and provides a way of identifying infrastructure that should be prioritized for repair (Roberts, 2015). Criticality ratings or scores can be used to rank the importance of infrastructure lines or facilities in relation to the type or amount of end users it services (Salem & Salman, 2012). In New Zealand, infrastructure lifeline groups assign infrastructure components with a rank based on:

- the number of customers that the line services (local, regional or national influence),
- the type of end users (e.g. infrastructure that services emergency facilities such as hospitals would have a higher importance than infrastructure that services entertainment venues),
- the consequences of the infrastructure failing, such as posing a risk to life, economic loss or social/cultural impacts (Auckland Engineering Lifelines, 2012; Aurecon and Bay of Plenty Lifelines Group, 2014; Roberts, n.d; Roberts, 2015; Table 2.2).

Different infrastructure networks (e.g. transport, electricity, water, communications and sewage), can also be weighted to consider important interactions. Communication infrastructure may be considered the most vital during an emergency, thus assets may have a high criticality. However, electricity lines that service those communications assets are required for functionality, thus the electricity asset can be weighted to consider the dependency (Roberts, 2015). Criticality ratings can also be applied to hotspots and pinchpoints (Roberts, 2015).

Table 2.2. Example of how infrastructure may be ranked/scored and weighted. Retrieved from Roberts (2015).

Score	**Service Failure Impact**
5	Affects most of region or national impacts (Criticality 1a)
4	Affects significant part of region > 100,000 customers (Criticality 1b)
3	Affects significant part of region > 20,000 customers (Criticality 2)
2	Affects significant local area > 5,000 customers (Criticality 3)
1	Affects minor localized areas
0	None
Score	**Affect on LoS**
4	Complete loss of service to impacted customers
3	Significant loss of service to impacted customers
2	Moderate loss of service to impacted customers
1	Minor loss of service to impacted customers
0	No affect on service provision
Score	**Weight**
4	Road/Electricity/Water
3	Telecommunications
2	Gas
1	Public Transport

2.1.3.3 Asset Vulnerability Metrics

Asset vulnerability metrics allow the severity of damage to be estimated based on the magnitude of a hydrodynamic parameter (such as inundation depth or flow velocity) and the potential, or lack thereof, to resist damage. Metrics can be qualitative or quantitative (Papathoma & Dominey-Howes 2003; Koshimura, 2009; Power 2013a).

Common vulnerability metrics include fragility functions/curves, damage functions/damage levels and damage matrices:

- Fragility functions are quantitative tools that describe the probability of damage for various hazard parameter intensities (Koshimura et al., 2009; Mas et al., 2012; Power 2013; Horspool & Fraser 2015). For example, when a wastewater treatment building is subjected to 4 m inundation, there is a 50% chance of extensive damage to the asset (Figure 2.11).

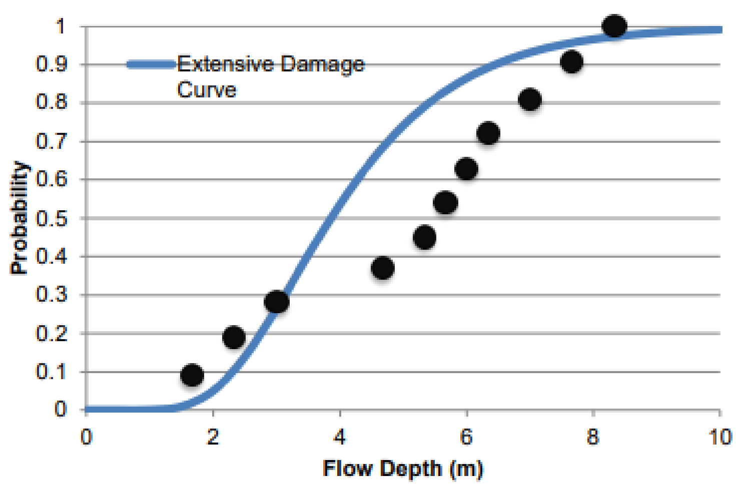

Figure 2.11. Fragility function for estimating the probability of extensive damage to wastewater treatment buildings (blue trend). The black dots represent data collected from damaged wastewater treatment buildings from the 2011 GEJ Tsunami. Retrieved from Horspool & Fraser (2016, p.40).

- Damage functions estimate a damage ratio for various hazard parameter intensities (Reese et al., 2007; Figure 2.12). Damage ratios can be relative to replacement cost or levels of damage such as minor damage through to collapse). Reese et al., (2007) estimate 80% of a timber building would be damaged if subjected to 2 m inundation above floor height.

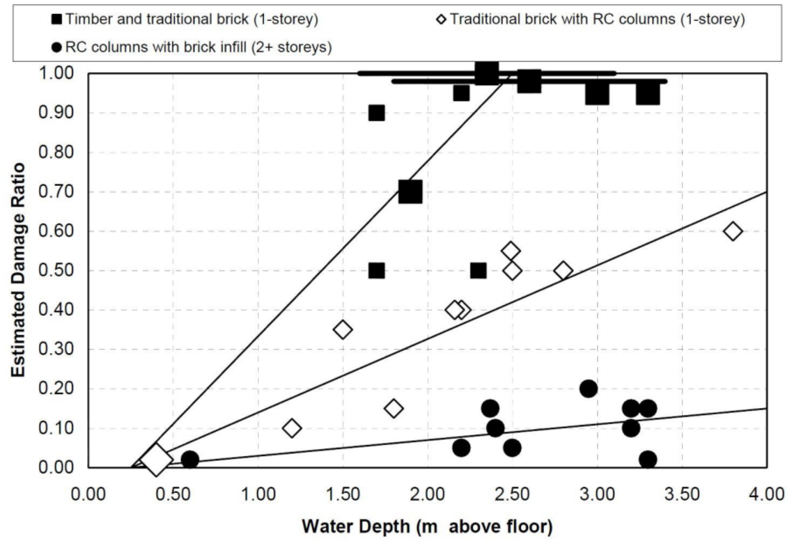

Figure 2.12. Damage function for buildings of various construction types constructed from data collected post 2006 Java tsunami. Retrieved from Reese et al., (2007, p.584).

- Damage matrices are qualitative metrics which provide a probability of damage and a description of the type of damage expected for various hazard parameter intensities (Horspool & Fraser, 2016). Table 2.3 indicates that for road pavement subjected to 2 m or greater inundation depth, there is a high probability complete washout would occur (Williams, 2016).

Infrastructural Asset	*Flow Depth < 0.5m*		*Flow Depth 0.5m – 2m*		*Flow Depth >2m*		*Data Quality*
	Probability of Damage	*Damage Type*	*Probability of Damage*	*Damage Type*	*Probability of Damage*	*Damage Type*	
e.g. road pavement	*e.g. low*	*e.g. siltation*	*e.g. medium*	*e.g. scour*	*e.g. high*	*e.g. washout*	*e.g. high*

Table 2.3. An example of a tsunami damage matrix. Retrieved from Williams (2016, p.35).

Vulnerability metrics are developed by analysing data collected from post-event field surveys, remote sensing, numerical modelling, historical documentation and analytical techniques (Williams, 2016; Scheele, 2016). When conducting an impact assessment, local vulnerability metrics generated for comparable infrastructure are preferred to overseas equivalents (which can be different in design and operation) (Williams, 2016). A summary of available and applicable fragility and damage functions for Christchurch (South Island, New Zealand) infrastructure was evaluated by Williams (2016), provided in Table 2.4.

Table 2.4. Most applicable vulnerability metrics for infrastructure in Christchurch. Retrieved from Williams (2016, p.39).

Infrastructure Asset	Highest Resolution Vulnerability Metric	Data type	Data Source
Wharves	Damage Matrix	Qualitative	Chapter 2
Fuel Storage Tanks	Damage Curve	Semi quantitative	(Hatayama 2014)
Roads (Generic)	Fragility Curve	Quantitative	Chapter 3, Horspool & Fraser 2015
Roads (Use Type)	Fragility Curves	Quantitative	Chapter 3
Bridges	Damage Matrix	Qualitative	Chapter 3, Horspool & Fraser 2015
Rail	Damage Matrix	Qualitative	Chapter 2
Wastewater Pipes	Damage Matrix	Qualitative	Chapter 2
Wastewater Pump Stations	Damage Matrix	Qualitative	Chapter 2
Potable Water Pipes	Damage Matrix	Qualitative	Chapter 2
Stormwater Pipes	Damage Matrix	Qualitative	Chapter 2
Open Drains	Damage Matrix	Qualitative	Chapter 2
Cellular Towers	Damage Matrix	Qualitative	Chapter 2
Utility Poles	Fragility Curves	Expert judgement	Horspool & Fraser 2015
Substations	Fragility Curves	Expert judgement	Horspool & Fraser 2015

Williams (2016) generated a damage matrix to offset the lack of available or applicable damage metrics to assess tsunami impacts on infrastructure in Christchurch (Appendix F). “It equates to a summary of all relevant and available literature containing a degree of infrastructural asset damage and/or hazard intensity relationship… and includes observations made during a post-event field survey following the 2015 ‘Illapel’ earthquake tsunami in Chile… in the city of Coquimbo” (Williams, 2015, p.35). This matrix appears to be the first of its kind. It provides a probability of damage occurring for three inundation depth classes and describes the damage type that may be expected (similar to Table 3). An update of this matrix is provided by Horspool and Fraser (2016, p.83-87, Appendix F).

2.1.3.4 Impact Evaluation

From the combination of hazard and exposure aspects using vulnerability metrics, impacts can be derived from either a probability of damage (fragility curve), percentage of damage (damage function) or a description of likely damages to occur (damage matrix). This information can then be used to infer damage states that describe a degree of damage in relation to ability to function i.e. impact. Damage states can then be used to determine LoS; both are useful for informing readiness, response and recovery planning.

2.1.3.4.1 Damage States (DS)

Road damage from the 2011 Great East Japan (GEJ) tsunami was recorded during a post-tsunami survey using damage states; roads were assigned a state according to the degree of damage (MLIT, 2012; Horspool & Fraser, 2016). These states included damage state 1 (minor damage but still functional), damage state 2 (one lane damaged, other lane passable) and damage state 3 (entire carriageway damage had occurred and the road was impassable) (Horspool & Fraser, 2016). Damage states have since been used to illustrate impacts, providing a holistic view of how a region's infrastructure and building stock may be damaged during a tsunami event (Williams, 2016; Williams 2016a; Scheele, 2016; Table 2.5). Assigning damage states from the information that vulnerability metrics provide is useful for emergency services, infrastructure providers and customers to inform readiness response and recovery initiatives. Areas susceptible to damage can be identified and prioritised for mitigation solutions (Williams, 2016).

Table 2.5. Building damage states for tsunami damage, developed by (Suppasri et al.,2013). Retrieved from Horspool & Fraser (2016, p.47).

Damage State (DS)	Description
DS1: Minor	Minor flooding, no significant damage to structure
DS2: Moderate	Slight damage to non-structural components and contents
DS3: Major	Heavy damage to some walls but not columns
DS4: Complete	Heavy damage to walls and some columns
DS5: Collapsed	Destructive damage to more than half of walls and columns
DS6: Washed Away	Structure washed away with only foundation remaining

Following the 2011 GEJ tsunami, fragility functions have been developed to estimate damage states (Suppasri et al., 2013; Horspool & Fraser, 2016).

2.1.3.4.2 Level-of-Service (LoS)

Level-of-Service is the overall usability of a specific site (which may be a network line, component or facility) following disruption, sometimes also called functionality states or serviceability (Blake et al., 2017; Robinson et al., 2015; Horspool & Fraser, 2016). LoS are different from damage states as LoS consider capacities in the network, mitigation measures that may reduce impact and allow function and, most importantly, societal exposure (Deligne, 2017). Infrastructure companies use LoS methods as a part of risk management, for customer care, maintenance and continuity (NZTA, 2013), and studies focusing on LoS as an output of natural hazard risk and impact assessments are increasing (Robinson et al., 2015; Buxton et al., 2014; Horspool & Fraser, 2016; Williams, 2016; Scheele, 2016; Blake et al., 2017; Deligne et al., 2017).

Common service levels range from no service (no function) to full service (fully operational) with a variety of intermediate levels that represent partial service (semi-functional) specific to a particular asset. LoS metrics provide a description of the criteria used to apply service levels (Table 2.6). These criteria can be developed through expert elicitation, expert judgement and literature review (Deligne, 2017; Cooke & Goossens, 2004). These methods can also be applied to develop metrics that relate damage states to a particular LoS (Table 2.7).

Table 2.6. Metric designed for assigning LoS to ports following volcanic impact. Retrieved from Blake et al., (2017, p.102)

Value	Port Level-of-Service	Example situations that could lead to LoS
I	Full service – port fully open	
II	Partial service	• Volcanic deposits affect operations at the port or navigation of vessels • Evacuation zone affects some navigation routes • Staff unable to access port facilities
III	No service – port closed	• Port destroyed or severely damaged beyond repair • Severe sedimentation in shipping channels means vessels cannot operate • Port closed due to being in evacuated area

Table 2.7. Damage states with resultant levels of serviceability. Retrieved from Horspool & Fraser (2016, p.80).

Damage State	Description	Serviceability
Damage State 1 (Rank C)	Minor damage, often from impacts, to the superstructure.	Operating as normal, needs minor repairs
Damage State 2 (Rank B)	Major damage to superstructure but still in place on piers. Superstructure may have been shifted.	Operating under speed and load restrictions or not operating if superstructure has shifted. Requires moderate-major repairs. If superstructure has moved bridge may need to be demolished.
Damage State 3 (Rank A)	Complete washout of superstructure	Not operating. Bridge will need to be rebuilt on new piles.

2.1.4 Tsunami Risk Management

The Risk Management Framework discussed in 1.3.5 is used in New Zealand to reduce tsunami risk. Tsunami risk management in New Zealand has focused on risk identification and identifying tsunami sources and likelihoods; it is still largely in the process of evaluating what assets are exposed. Effort has also been applied to treating risk, as discussed in the following subsections.

2.1.4.1 Tsunami Risk Reduction in New Zealand

Recent destructive tsunami events including the 2004 Indian Ocean tsunami, 2009 Samoan and 2011 GEJ tsunami have prompted interest from scholars worldwide and national-level investment in tsunami risk. In 2005, the New Zealand Government sought to assess tsunami hazard and risk to New Zealand. The Ministry of Civil Defence and Emergency Management (MCDEM) commissioned GNS Science to prepare a 'science report' summarising existing information on tsunami risk and a 'preparedness report' to review existing arrangements and frameworks that reduce this risk and guide effective response and recovery (Berryman, 2005; Webb, 2005). Berryman (2005) concluded that tsunami risk was much higher than previously assumed. As a result, Webb (2005) recommended that substantial investment was required to better understand New Zealand's tsunami risk.

Power (2013) subsequently produced an update on tsunami hazard quantification and impacts that included a nationwide probabilistic calculation of tsunami hazard forming a basis for a New Zealand national tsunami hazard model. Following this work, Power (2013a) and GNS Science (2014) produced probabilistic tsunami hazard curves and deaggregation plots for 20-kilometer sections of New Zealand's coastline and a database of historical tsunami impacts was generated (GNS Science, 2014). Horspool, Cousins & Power (2015) updated this work, quantifying national tsunami risk in terms of impacts on people and the environment. The New Zealand Institute of Economic Research (NZIER, 2015) carried out a public policy analysis of New Zealand's tsunami risk and capability to manage a tsunami event. NZIER (2015) found that potential tsunami impacts and the responses required are not widely understood due to lack of direct experience; and that while the annual fatality risk from tsunami in New Zealand is comparatively high, expenditure in assessing and managing this risk is low.

A systematic review of tsunami hazard, assessment and risk literature by King (2015) found that knowledge of tsunami risk has greatly improved in respect of cataloguing tsunami impacts, scenario-based modelling, mapping of offshore tsunami sources and palaeo-tsunami investigations, as well as planning and preparedness (King, 2015, p.37). However, like Power (2013a) and NZIER (2015), King (2015) states that more research is required to understand tsunami hazard and risk in New Zealand.

Subsequent investigations have focused on a range of aspects to better understand tsunami risk for New Zealand; cataloguing of palaeo-tsunami records (New Zealand Palaeotsunami Database, 2017), improving tsunami inundation modelling (e.g. Lane et al., 2011), improving understanding of tsunami sources for New Zealand (e.g. GNS, n.d), development of vulnerability metrics for New Zealand infrastructure for impact assessments (Horspool &Fraser, 2015; Horspool & Fraser, 2016; Williams, 2016; Scheele, 2016), developing loss modelling tools such as RiskScape, investigating public tsunami warning and evacuation response (e.g. Fraser & Power, 2013), developing evacuation models (e.g. Le, 2016), improving national warning capability (MCDEM, n.d-c) and nation-wide development and implementation of tsunami evacuation zones (MCDEM, 2016).

However, as the International Red Cross and Red Crescent Societies state, "continued work and investment is required for implementation to fully succeed, notably in hazard-prone areas with a small population base, where resources for DRR are based on local taxes (rates) rather than local risk levels," (IFRC, 2014, P.5).

2.1.4.2 Past and current tsunami risk reduction initiatives for the Chatham Islands

To date, research contributing to understanding tsunami risk to the Chatham Islands has been primarily focused on hazard assessment, including cataloguing historical and recent tsunami impacts, palaeo-tsunami investigations, probabilistic hazard curves and deaggregation plots, scenario-based hydrodynamic modeling and rule-of-thumb (level 2) evacuation zone modelling.

2.1.4.2.1 Cataloguing historical and recent tsunami impacts

Some effort has been made to investigate historical and pre-historic tsunami on the Chatham Islands (De Lange and Healy, 1986; De Lange and McSaveney, 2009; GNS Science, 2014; GeoNet, n.d-a; Geonet, n.d-b; Johnston et al., unpublished; Kain, 2011; Thomas, 2017). Table 2.8 shows the current status of information available for each event (Thomas, 2017).

Table 2.8. Summary of the current state of knowledge for historical tsunami events that have impacted the Chatham Islands. Tsunami intensities are based on the intensity scale reviewed by Lekkas et al (2013) and were retrieved from GNS Science (2014) and Barberopoulou & Scheele (2016). Intensities provide information on the damage extent of the event ranging from I (not felt) to XII (completely devastating) based on a range of factors including physical quantities of the tsunami and impacts on humans, property, infrastructure and the environment. Colours are used to represent current state of knowledge. Red represents poor to no knowledge; orange represents some knowledge; yellow represents more knowledge than orange but with uncertainties; and green represents information collected during investigations provides sufficient detail for hazard assessment. Following Thomas's investigation of the 1868 event, the impacts have been classified as green instead of yellow. However, the inundation extent has not been investigated in detail. Adapted from Thomas (2017).

Historical Tsunami Event	Tsunami Intensity	Source & Time Generated (NZST)	Tsunami Height	Time of Arrival	Number of Significant Waves	Inundation Extent	Impacts	References
1964	Unknown	Distant: Alaska Mw 9.2 March 29, 15:36						Johnston et al., unpublished
1960	V-VII	Distant: Chile Mw 9.4-9.6 May 23, 07:11						Johnston et al., unpublished; Geonet, n.d; Kain, 2011; GNS Science, 2014;
1952	Unknown	Distant: Kamchatka Mw 9.0 November 4, 04:58						Johnston et al., unpublished
1947	V-VIII	Regional: Gisborne Mw 7.0-7.1 March 26, 08:32						Johnston et al., unpublished; GNS Science, 2014; Geonet, n.d-b
1946	VI	Distant: Aleutian Islands Mw 8.1 April 2, 00:28						Johnston et al., unpublished; GNS Science, 2014
1924	IV-IX	Local: Uknown Source Uknown Mw July 19, arrival time at 18:30						Johnston et al., unpublished; GNS Science, 2014; De Lange & Healy, 1986; Geonet, n.d-a
1922	IV	Distant: Chile Mw 8.5 November 11, 16:02						Johnston et al., unpublished; GNS Science, 2014
1877	VIII	Distant: Northern Chile Mw 8.8 May 10, 12:29						Johnston et al., unpublished; GNS Science, 2014; Geonet, n.d-c
1868	IV - X	Distant: Southern Peru Mw 8.5-9.5 August 14, 09:00						De Lange & Healy, 1986; Geonet, n.d-d; De Lange & McSaveney, 2009; Goff et al., 2010; Nichol et al., 2010; Kain, 2011; Johnston et al., unpublished; GNS Science, 2014; Thomas, 2017

2.1.4.2.2 Palaeo-tsunami investigations

Dune morphology and remobilisation of the Kekerionian dunes provide evidence for pre-historical tsunami events in the Chatham Islands between 1350 AD and 1500 AD (McFadgen, 1994; Nichol et al., 2010; The New Zealand Palaeotsunami database, 2017). McFadgen (1994) also documented Tua Tua shells in layers of peat at Te Awapatiki; the shells were dated at 15000-16000 BP providing evidence for a potential tsunami event around 14000 BC - 13000 BC (The New Zealand Palaeotsunami database, 2017). Goff et al. (2010) and Nichol et al. (2010) identified sedimentary evidence of the 1868 tsunami event preserved in a wetland, and as gravel lags on the sand dunes at Okawa Point (northern point in Figure 2.13). Sedimentary evidence of the 1868 event was also found at Tupuangi near the house ruins (Goff et al., 2010). An earlier tsunami event was also discovered by Goff et al. (2010) at Cape Pattison and inferred to be the 1604 AD tsunami event. Kain (2011) investigated physical tsunami signatures near the tsunami ruin in Te Raki Bay. Currently a joint Tohoku University-UNSW research project is researching the palaeo-tsunami boulders at Okawa Point (southern point Figure 2.13) (J. Goff, UNSW, personal communication, January 2018).

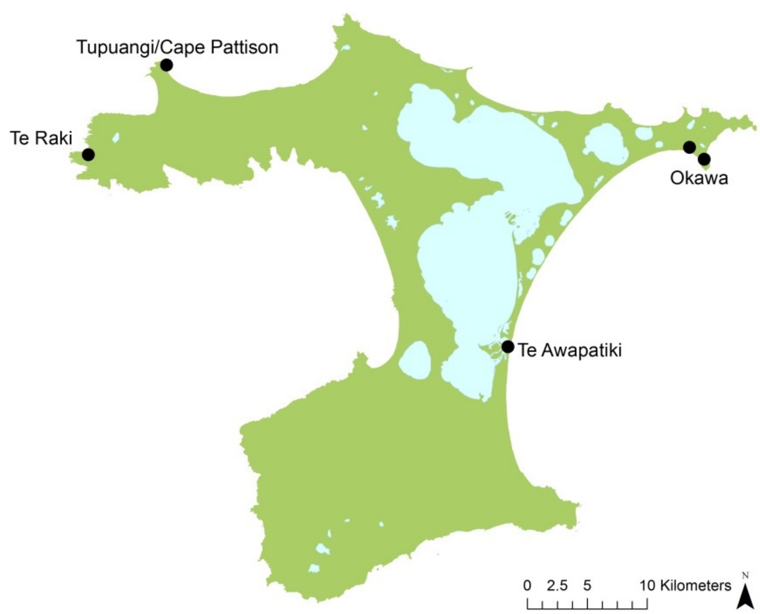

Figure 2.13. Map of palaeo-tsunami investigations on the Chatham Islands by McFadgen (1994), Goff et al., (2010), Nichol et al., (2010) and Kain (2011). Data retrieved from LINZ (Island polygons and waterbodies).

2.1.4.2.3 Probabilistic hazard curves and deaggregation plots

Deaggregation plots were produced to show the relative probability of each (known) source triggering 500 and 2500 yr return events that would affect the Chathams (Figure 2.14) (Power, 2013b). According to the deaggregation plots, subduction zone earthquakes from Peru, Central Chile, the Kermadec Trench (A-NZ), Hikurangi Subduction Zone (A-NZ), Northern Chile, the Kuril Kamchatka Trench (Japan), and the Aleutian Trench (Alaska) are likely tsunami sources for the Chatham Islands (Power, 2013b). Of these sources, the Peruvian subduction zone represents the greatest frequency of large magnitude events followed by Central Chile, Hikurangi Trough and Japan. However, it should be noted that probabilistic models are associated with large uncertainties from both earthquake sources and modeling (Power, 2013; Power & GNS Science, 2014; Davies et al., 2015).

Probabilistic hazard curves for the Chatham Islands were also produced by Power (2013b) showing predicted wave heights at the coast for given return periods (Figure 2.15). These were generated by the national probabilistic tsunami hazard model developed by Power (2013a). According to the hazard curves, the settlement of Owenga is exposed to the greatest hazard as it has the steepest mean hazard curve (expected 10 m tsunami wave height at the coast for a 500 yr return event), followed by Kaingaroa (expected 8.4 m tsunami for a 500 yr return event) then Waitangi (expected 7 m wave for a 500yr return event) (Table 4.1).

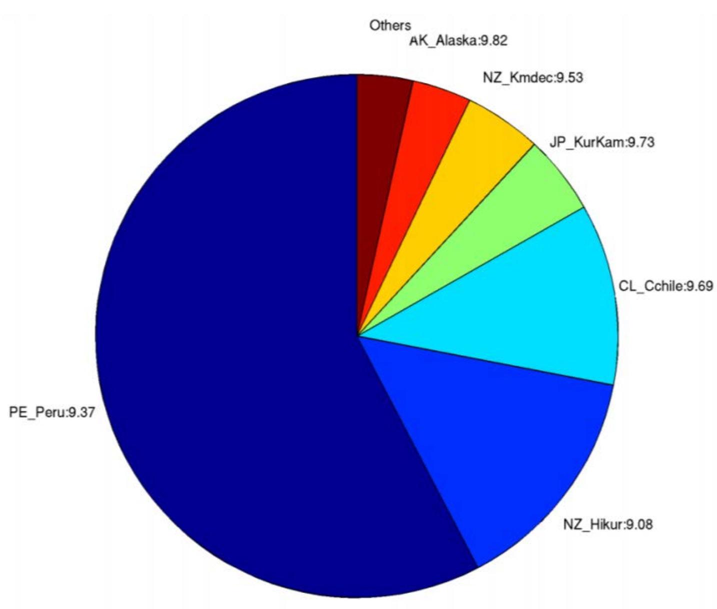

Figure 2.14. Deaggregation plot produced for Point Durham coastline for a 2500 yr return event. Retrieved from Power, 2013b, p.515.From largest proportion to smallest, sources are: Peru, Hikurangi, Central Chile, Japan, Kermadec, Alaska and others/unknown sources.

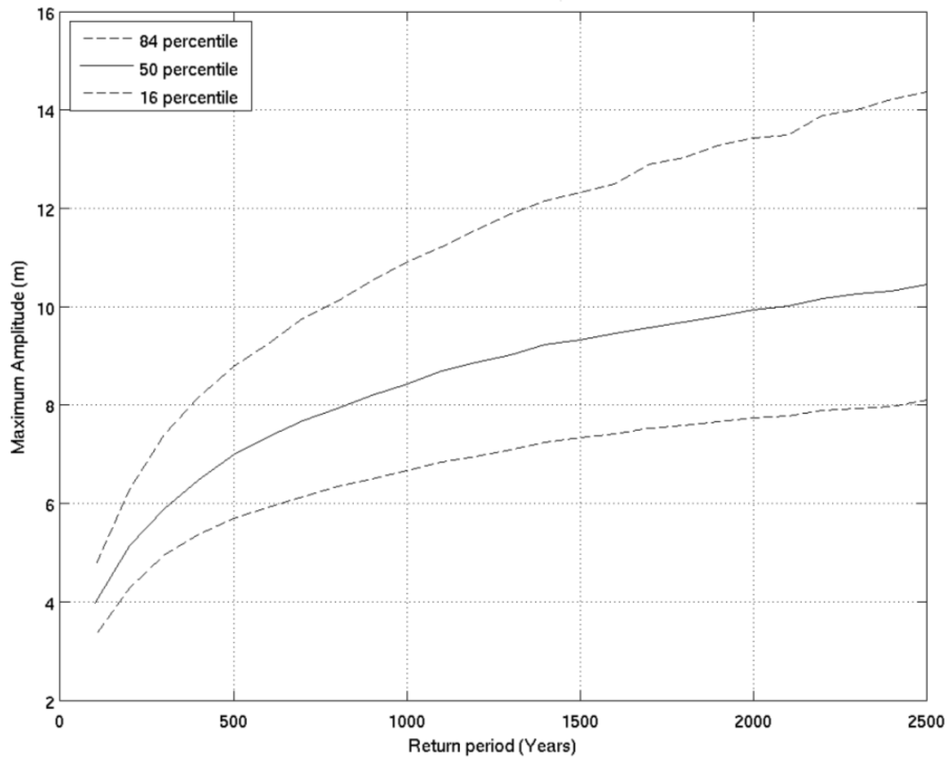

Figure 2.15. Hazard curve produced for Point Durham coastline on the Chatham Islands which includes Waitangi. Retrieved from Power, 2013b, p.514.

2.1.4.2.4 Scenario-based hydrodynamic modeling

The National Institute of Water and Atmosphere (NIWA) was commissioned by the Chatham Islands Council (CIC) to conduct numerical modelling of tsunami inundation to inform tsunami evacuation zones and future emergency management planning (Lane et al., 2016). Regional- and distal-source tsunami (based on 2500 yr return periods at the 84% confidence interval) were modelled to estimate inundation particularly in Waitangi, Owenga, Kaingaroa and Port Hutt. While it is recognised that local source tsunami from submarine landslides and slumping on the Chatham rise present a hazard to the Chatham Islands, little is known about these potential sources and insufficient data are available for model input so a local scenario could not be modelled (Lane et al., 2016).

According to Power (2013) an earthquake on the Hikurangi - Kermadec subduction zone represents a primary source for regional tsunami hazard to the Chatham Islands. GNS Science were contracted by Environment Canterbury Regional Council (ECan) to produce Hikurangi source tsunami models. The purpose of these source models was inform a worst-case tsunami scenario for the Chatham Islands to be used for hydrodynamic and level 2 (rule-of-thumb) tsunami modelling for the generation of evacuation zones (Mueller et al., 2016). Based on requests from ECan, Mueller et al., (2016) advised that a Mw 9.1

rupture with variable slip along the southern segment of the Hikurangi fault was the most plausible scenario that produced maximum credible wave heights at Kaingaroa and around the Chatham Islands coastline (Figure 2.16). This scenario was modelled by Lane et al., (2016), assuming a wave arriving at mean high water spring tide (MHWS), 0.6m above mean sea level (MSL).

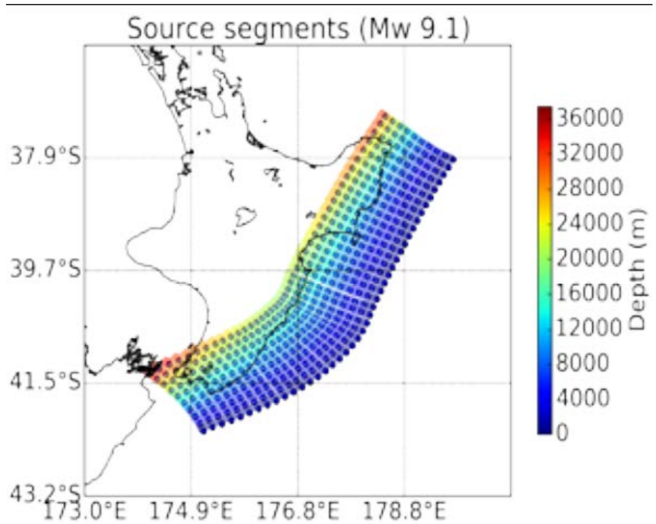

Figure 2.16. Source segment used for regional - Hikurangi source tsunami scenario for hydrodynamic modelling. Retrieved from Mueller et al., 2016.

According to Power (2013b) the most likely scenario representative of a worse-case (2500-year return period at the 84th percentile) event is a Mw 9.485 earthquake originating in Peru. Thus, this event was modelled to represent the distal source tsunami, arriving at MHWS to represent a worst-case scenario. Four rupture scenarios were modelled, all Mw 9.485 but on different fault segments and having varied displacements. Scenario B (Top Right in Figure 2.17) produced the maximum wave height and inundation extent of the four rupture scenarios (Lane et al., 2016).

Hydrodynamic tsunami modelling conducted by NIWA used Gerris and RiCOM tsunami models. “Gerris was used to model the trans-Pacific tsunami propagation from source, forming the boundary conditions for the higher resolution inundation modelling carried out using RiCOM.” (Lane et al., 2016, p.15). The accuracy of tsunami modelling results is largely dependent on near-shore bathymetry and coastal topography. A Digital Elevation Model (DEM) was generated from photogrammetry and extensive corrections were made by NIWA to both the DEM and bathymetric data in order to better represent the true topography to the best of available knowledge. The revised DEM has a resolution of 2 m. The open ocean grid has a resolution around 2 km, this was then refined to around 150 m around the coast. Bathymetry offshore of Waitangi, Port Hutt, Owenga and Kaingaroa was further refined to 15-20 m. A land grid at a similar resolution was then created and attached to the bathymetric grid (Lane et al., 2016). However, due to the quality of the data, high uncertainty is associated with the modelling results. As a result, inundation may be considerably under- or overestimated (Lane et al., 2016). Models are only representations of reality, and uncertainties lie in both the Gerris and RiCOM modelling by way of simplifying assumptions (Lane et al., 2016). Uncertainties are also involved in the source location and characteristics of the source fault ruptures for both scenarios (Lane et al., 2016).

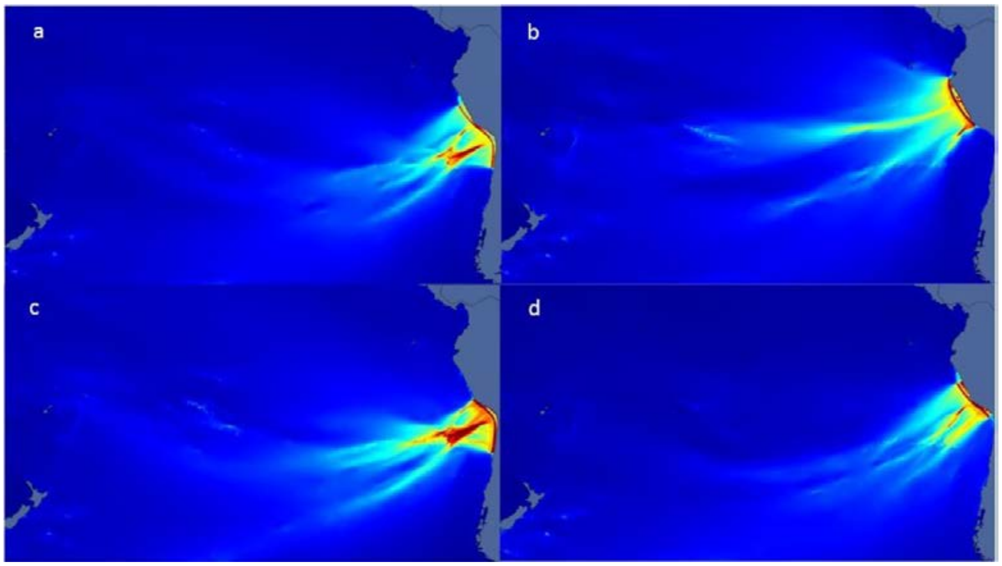

Figure 2.17. Four Peruvian rupture scenarios modelled. Scenario a had a 20.0 m slip, scenario b: 26.3 m slip, scenario c: 24.7 m slip, and scenario d: 23.4 m slip (Lane at al., 2016).

2.1.4.2.5 Rule-of-Thumb (Development Level 2) Evacuation Zone Modelling

Tsunami evacuation zones in A-NZ can be developed using a variety of techniques; but the zones need to encompass all areas subject to inundation produced by all possible tsunami sources (MCDEM, 2016a). Rule of thumb (ROT) (also known as development 2 modelling) is an empirical Geographic Information System (GIS) - based approach. An attenuation rule is applied; the potential run-up height at the coast (taken to be twice the shoreline wave amplitude above high tide) decreases with distance inland from the coast, according to a specified slope angle (MCDEM, 2016a, Figure 2.18). Inundation extents (which are representative of the events likely to produce the modelled wave amplitude) are located where the attenuation line intersects with topography. This type of modelling was developed by Leonard et al., (2008); the attenuation rules (which differ for inundation on land, up rivers and for river overspill) were calibrated using empirical data from post-tsunami field surveys. ROT modelling methods were validated by Fraser & Power (2013) who compared outputs of the attenuation-rule to inundation and run-up observed during the 2011 GEJ Tsunami. However, as MCDEM (2016a) note, local knowledge must also be applied to support ROT model derived zones.

ROT models are the recommended approach when high quality (LiDAR-grade, better than 1 m vertical resolution) topographic and bathymetric data are not available. This is partly because hydrodynamic models (development levels 3 and 4) are more uncertain when low accuracy data are used for input parameters (MCDEM, 2016a). ROT modelling provides a more realistic output than development level 1 bathtub modelling (in which inundation is based on wave amplitudes projected inland from the coast to some cut-off elevation) but still does not incorporate physical variations in tsunami wave behavior. Because the model does not incorporate complex tsunami wave behavior influenced by aspects such as ground cover and geomorphology, the models are generally conservative, or overestimate the inundation extent. This allows the modelled zones to cover a range of scenarios (MCDEM, 2016a). ROT models for the Chatham Islands were developed by ECan and applied for 3m, 5m, and for 500 and 2500-year probabilistic wave heights (8 m for 500 yr return period and 9.5 to 21 m for 2500 yr return period) provided by Power (2013a) (H. Jack, ECan, Personal communication, February 2017).

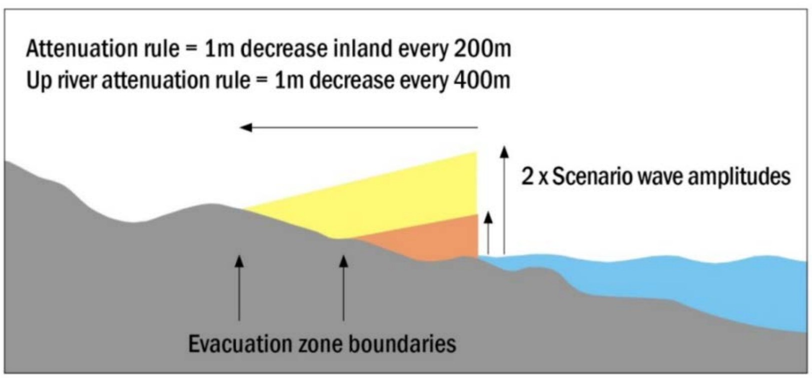

Figure 2.18. Rule of thumb modelling showing how evacuation zones are determined. Retrieved from MCDEM (2016) p.15.

2.1.4.2.6 Existing tsunami DRR initiatives on the Chatham Islands

Existing tsunami risk reduction initiatives on the Chatham Islands have been informed by these hazard assessments and have been developed under statutory obligation by the Chatham Islands Council (CIC), or by interest of other government organisations. Contributions are as follows:

- GeoNet operates a tsunami gauge at Owenga Wharf to detect tsunami. A seismometer station and a continuous Global Positioning System (GPS) monument are also installed on Chatham Island, at Wharekauri Station. Data from these devices are received by the GeoNet Data Centre in Wellington via satellite (GeoNet, 2008).

- Under statutory requirements of the CDEM Act 2002, CIC has developed the following plans: Tsunami Warning Plan, Evacuation Plan, Emergency Communication Plan, Emergency Operation Centre (EOC) Plan, Welfare Centre Emergency Plan and Recovery Plan. These plans outline key procedures, specific actions, available resources and responsibilities of both emergency personnel and the community during receipt and dissemination of warnings, establishment of an EOC, the evacuation of areas and communication during a tsunami event. These plans are currently under review.
- ECan and CIC developed tsunami evacuation zones for the Chatham Islands in 2017 and are reviewing the plans mentioned above during 2018.
- Exercise Tangaroa, a national CDEM exercise conducted in 2016 to test New Zealand's preparedness for a regional source tsunami, also involved the Chatham Islands CDEM Group (H. Jack, Ecan, personal communication, 7 April 2016; MCDEM, 2016).

However, current initiatives are limited by a lack of understanding of exposure and impacts to inform more effective preparedness, response and recovery plans. Little prior research has contributed to understanding exposure, vulnerability and risk for the Chatham Islands.

Engagement with the community on the present project began in November 2016 when conversations started with Local Government representatives, Iwi, infrastructure companies and scientists involved in tsunami research on the Chatham Islands to identify information gaps and potential project objectives that would provide useful information to the community. Of interest to ECan and CIC is historical event information to help verify tsunami evacuation zones and to improve the current understanding of tsunami hazard. Scientists from NIWA and the University of New South Wales (UNSW) suggested more palaeo-tsunami investigations to identify other parts of the island that were inundated in the past (J. Goff & D. King, personal communication, November 2016). It is also important to ECan, CIC, the Canterbury Civil Defence and Emergency Management (CDEM) Group, infrastructure companies on the Chatham Islands, Iwi and the wider Chatham Islands community to assess potential tsunami impacts on lifeline infrastructure. During a high-impact tsunami event that also affects mainland A-NZ, the Chatham Islands may be isolated from external assistance and off-island resources for considerable time as larger affected populations may be prioritised in response efforts; thus performance of infrastructure components and essential services will be vital. Iwi suggested community education and awareness of tsunami hazard, and what the community can do to be prepared.

3 HAZARD CHARACTERISATION

3.1 INTRODUCTION

The Chatham Islands are exposed on all sides to local, regional and distant source tsunami. The review of tsunami risk reduction initiatives in Section 2.1.4.2 revealed several contributions have been made towards understanding tsunami hazard for the Chatham Islands. However, due to limitations associated with previous contributions outlined in Section 2.1.4.2, further research is required to better characterise tsunami hazard for the Chatham Islands. Of particular interest to ECan and Chatham Islands Council (CIC) is more historical event information to help verify tsunami evacuation zones, and to improve the current understanding of tsunami hazard to better inform future risk reduction initiatives.

The purpose of this chapter is to address objective 2: explore documented accounts and Tangata Whenua knowledge, and/or local knowledge (knowledge of people who have lived on the Islands for a long time but who do not have indigenous ties to the island), of past tsunami inundation and impacts on the Chatham Islands. Firstly, some context is provided for investigating historical events through researching documented accounts and exploring Tangata Whenua and local knowledge. The methodology is then described, followed by results presented in the form of tables and maps. The results provide detailed accounts of historical tsunami events, their inundation and impacts, to help inform future DRR initiatives on the Chatham Islands. This information is part of the risk identification process and will be used to develop an inundation scenario (Chapter 4) for input into the tsunami impact assessment (Chapter 5). Finally, a discussion of the methodology and results is presented.

3.2 CONTEXT/EXTENDED LITERATURE REVIEW

Of particular interest to this project's stakeholders are historical tsunami inundation extents and impacts. Thomas' (2017) investigation of the 1868 tsunami event revealed a substantial amount of information recorded in newspapers, letters, diaries and books that had not been included in national databases (GNS Science, 2014; New Zealand Palaeo-tsunami Database, 2016). That study recommended further investigation into other events such as 1877, 1924, 1946 and 1960 to improve current knowledge of impacts of other historical events on the Chatham Islands.

Kain (2011), Johnston et al. (unpublished) and Thomas (2017) recognised the potential value of exploring local oral history and Tangata Whenua knowledge of tsunami that have affected the Chatham Islands:

- Kain (2011) recorded stories told by landowners when investigating palaeo-tsunami records.
- Johnston et al. (unpublished) collected eyewitness accounts from two Chatham Islanders who experienced the 1960 tsunami.
- Thomas (2017) found that Māori prophesies predicting tsunami inundation existed before the 1868 event. Māori were also quick to evacuate following any predictions of tsunami, this presumably being due to previous experience of events (Jumping Claims, 1895). This investigation also found that more fatalities occurred in the 1868 event than currently documented in national databases (1 fatality). Thomas (2017) was informed of a diary that records 23 or 32 deaths at the Māori Pā Tupuangi due to a "tidal wave" in 1868 (Chatham Island resident, personal communication, November, 2016). The diary is yet to be found.

On Wharekauri-Rekohu-Chatham Islands, 59.3% of the population identify as being Māori (Statistics New Zealand, 2013). It is estimated that Māori and Moriori people arrived at the Chatham Islands sometime between 1,000 to c. 450 years BP and have inhabited the islands since (Sutton, 1980 cited by McFadgen 1994). Although, during this time and until present, multiple phases of arrival and departure of Māori occurred. It is likely that Māori and Moriori people would have witnessed multiple tsunami events over this time.

Apart from the contributions listed above, Māori and Moriori knowledge of tsunami on the Chatham Islands is undocumented. The present research presented a unique opportunity to explore local knowledge and/or Tangata Whenua knowledge of tsunami from an internal perspective (the author is also Tangata Whenua).

3.3 Methodology

The methodology used to explore impacts and inundation extents of past tsunami events on the Chatham Islands does not fit neatly into any one category, but uses a combination of methods and multidisciplinary approaches. Historical tsunami event information was collated both from documented accounts (including newspapers, diaries, photographs, paintings, maps) and from interviews with Tangata Whenua (people of the land), referred to individually as key informants (Figure 3.1). The information for each event was then combined and organised into themes of impact types and locations to provide a detailed description of the 1868, 1877, 1924, 1946, 1947 and 1960 tsunami events. Both sources were also used to evaluate the inundation extents of historical events. The methods used for each step of this process are described in detail in the following sub-sections.

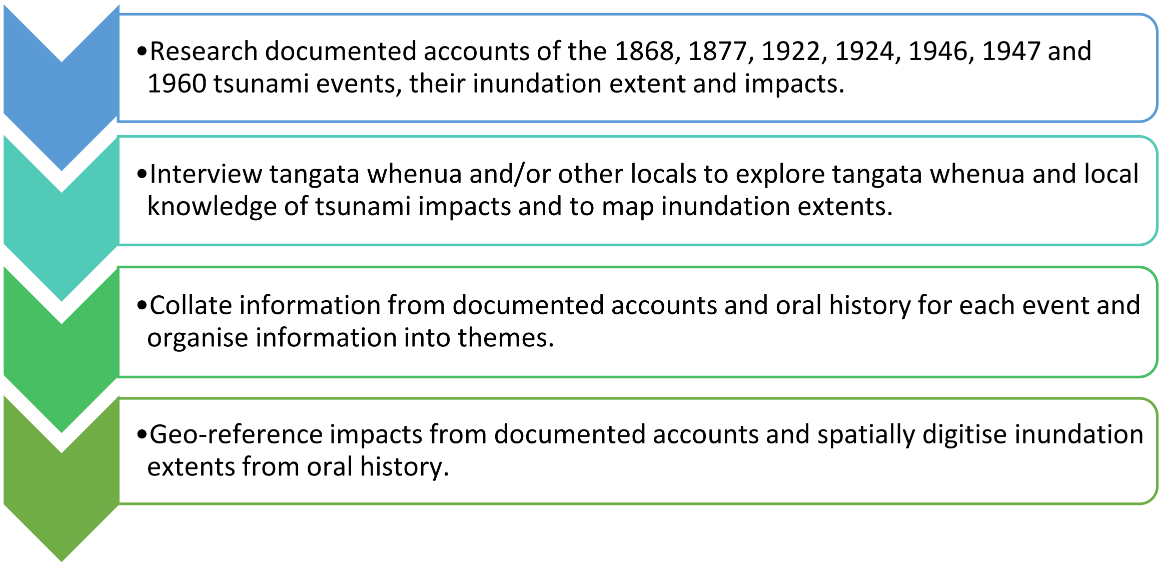

Figure 3.1. Chapter two methodology.

3.3.1 Researching Documented Accounts

A literature review approach was used to search library archives and museum collections for information on Chatham Island tsunami including:

- University of Canterbury Library (Christchurch).
- Alexander Turnbull Library (Wellington).
- Christchurch City Libraries (Christchurch).
- Chatham Islands Museum (Chatham Islands).
- Papers Past online collection of newspapers.

Key words including the following were searched: tsunami, tidal waves (what people used to call tsunami events before the term tsunami came into common usage), Chatham Islands, dates the events occurred and impacts that occurred in each event (e.g. shipwrecks, factory damage and others recorded in Table 10). The investigation included two visits to the National Library Archives (Alexander Turnbull Library) in Wellington to search for tsunami accounts and the diary that reportedly holds the number of deaths that occurred in 1868.

Other archives were also searched. Somerville (in Anderson & O'Brien, 2017) describes archives not only as libraries, museums and places with the word 'archive' on the front door, but also other places where things, people, and ideas come together. Texts that record Indigenous knowledge or stories of the past are likely to be found in archives such as the marae, the back shed, the hallway (e.g. as paintings on the walls), or the dusty box in the wardrobe (Somerville, A. T. P. in Anderson & O'Brien, 2017). Photographs and paintings, from which contemporary exposed assets were digitised, were often located in people's houses that the author happened to be visiting at the time, in relatives' bookshelves, in community halls (Kaingaroa Club and Owenga Club on the Chatham Islands), and even on Facebook (through a community page where old photographs are sometimes shared) and TradeMe (a popular buy-sell website in New Zealand where an old photograph of Waitangi was found). Ruins from the 1924 tsunami were also re-discovered by the author when visiting the area for another unrelated purpose. These places were not visited with direct intention of searching for Chathams tsunami-related items but often 'popped up' by chance. Mātauranga Māori involves a view that everything (nature, objects, people, places) has mauri – a life-force. There is a Māori view that if you find something (usually used in the context of taonga), the object wanted to be found, and was meant to be found by you.

3.3.2 Exploring Tangata Whenua and Local Knowledge of Tsunami

A literature review of Māori research methodologies in 2.3.1.4 guided the methods used to explore documented accounts and Tangata Whenua and/or local knowledge of tsunami in the Chatham Islands. An ethical approach was followed which respected kaupapa Māori research principles (Ch. 1). This involved engaging with Iwi and Imi in the research design and seeking advice from Māori researchers at NIWA and the Joint Centre for Disaster Research (Massey University Wellington). This approach was approved by the University of Canterbury Human Ethics Committee (Appendix D).

3.3.2.1 Ethical considerations

It is important to understand the cultural context and history of a place and its people before commencing research (Smith, 1999). This aligns with kaupapa Māori research principles (1.3.1.4.2.1) Titiro, whakarongo … kōrero (look, listen… then speak), aro ha ki te tangata (a respect for people) and Kia tūpato (to be cautious) (Smith, 1999). The Chatham Islands has a contested history of the relationships between Māori and Moriori people, misinterpreted by pākehā historians. Iwi (Māori tribe) and Imi (Moriori tribe) on the Chatham Islands are also currently undergoing Waitangi Tribunal Land Settlements. This process is stressful and causes historical conflicts to re-surface. The author was aware of both contexts and was mindful not to cause any undue stress to research participants. In order not to add to current divisions between Chatham Islanders who identify as being of Māori or Moriori descent, one category was defined to encompass all indigenous peoples. The term 'Tangata Whenua' refers to people of the land, which, "does not simply apply to all Indigenous Māori but to those who have bona fide lineal kinship and primary accountability to a specific community of a specific locale or region in question" (Diaz, V. M. in Andersen & O'Brien, 2017, p.91). Thus, for the purposes of this research, the term Tangata Whenua includes both Māori and Moriori people and Pākehā refers to people of European or other heritage who may possess local knowledge of tsunami events.

Signing of te Titiriri O Waitangi (the Treaty of Waitangi) is also a sensitive topic when engaging with Māori (Smith, 1999). To delve into the history and wrong-doings involved with Te Tiriti o Waitangi is beyond the scope of this research, but it was acknowledged that the signing of consent forms required for research purposes may be stressful for Tangata Whenua. Information sheets and consent forms are an essential part of informed consent in social science ethics and usually require participants to sign a consent form to indicate:

- that they are willing to participate in the research and are aware of all of the conditions involved with taking part in the research including around:
    - intellectual property rights over the knowledge shared,
    - the ability to withdraw or change material, or withdraw entirely from the research,
    - opportunities to review data from the interview,
    - who will be involved in viewing and processing the data,
    - future use and access of the data,
    - storage of the data,
- and to indicate preferred options concerned with identity and recording (Oral History Association, 2000; Davidson & Tolich, 2003; Love, 2012).

Sensitivities around Tangata Whenua signing consent forms were managed by providing participants with the option to sign the form, or provide oral consent – the Māori way of giving permission (Smith, 1999).

Participants who volunteered to take part in the research/share their knowledge chose to:

- Be named in the research or remain anonymous (assigned with a pseudonym),
- Provide their ethnicity or not (Tangata Whenua or pākehā or prefer not to say),
- Be electronically recorded or just allow note taking,

- Sign the form or give oral consent,

and were able to review their material and withdraw their material from the research at any time.

3.3.2.2 Recruitment process

The recruitment process was guided by the University Of Canterbury Ethics Committee and advice from Massey University's Joint Centre for Disaster Research. Firstly, both Ngāti Mutunga o Wharekauri Iwi Trust (NMOWIT) and Hokotehi Moriori Trust (HMT) were contacted to introduce the purpose and intentions of the project, and the ways in which the information collected in the thesis will be useful to Māori/Moriori of the Chatham Islands. Initial contact was made via email and/or phone call, and in-person meetings were arranged when visiting the Chatham Islands in November 2016. Both Iwi and Imi were supportive of the project's purpose and intentions.

Also discussed were the participant recruitment process and participants' rights if they agreed to be interviewed. Iwi and Imi agreed that advertising through local channels such as newsletters and Facebook pages inviting people to take part was a voluntary and ethical way of recruiting participants. A notice explaining the project and seeking participants was posted through the Ngāti Mutunga o Wharekauri Iwi newsletter, the Chatham Islands Community Focus community newsletter, and was posted on two Facebook pages ('Hokotehi Moriori Trust' and 'Chatham Islanders Worldwide') (Appendix E.2).

People often recommended contacting their family members and friends who they knew had knowledge of tsunami (via Facebook comments or messages). Such snowballing methods were not deemed appropriate for this study by the University of Canterbury Human Ethics Committee. In these situations, it would be explained that it was not ethical to approach people directly but would ask if the name-giver would kindly pass on the advertisement to the potential participant to get in contact if they wished to be involved.

Participants were provided with an information sheet about the project and a consent form, available in hardcopy from the local post office/bank (regularly visited by residents to collect mail and do banking) on the Chatham Islands, and was also attached to the Facebook posts (Appendix E.2).

3.3.2.3 Interview Methods

The interviews were semi-structured and informal, whereby a list of questions was pre-determined but the conversation was free to flow to explore different topics (Davidson & Tolich, 2003). The semi-structured interview approach was selected over other methods due to its informal nature and ability to explore relevant topics introduced by the participant (Love, 2012).

The interview explored the participant's knowledge of each tsunami in the sequence from 1868 to 1960. Each tsunami topic included questions to address uncertainties in evaluated documented accounts, followed by questions around their personal experiences or what they remembered hearing from their parents, grandparents or generations past.

Indigenous peoples hold a sense of place attachment formed by direct experiences, and/or indirect experiences through family history and culture (Hamilton & Shopes, 2008), including Māori, who have close association with their environment (King et al., 2007; King & Goff, 2010). Mapping tools are commonly used when investigating indigenous oral histories or public memories, to encourage story sharing and to record spatial information (Bethgate & Barrkman, 1998; Hamilton & Shopes, 2008). Mapping tools are also used in DRR to map hazard extents and exposed and vulnerable assets through methods such as participatory mapping (1.2.4.2.; Cadag & Gaillard, 2012; Twigg, 2004; DRR Working Group, 2012; Benson et al., 2007). Participatory mapping was considered for this project but was prohibited by the ability to physically gather the limited number of people who remembered tsunami on the Chathams in one room, as they were likely to be spread across the Chathams and New Zealand, or were on and off the Island at different times. Therefore, interviews were carried out individually following methods similar to those used by Hamilton & Shopes (2008) when mapping oral history/public memories. Photographs (Appendix E.1) and aerial photographs (2015 Google Earth Imagery) were used to explore Tangata Whenua knowledge of impact localities mentioned in documented accounts, and also to map recollections of inundation extents. Participants were asked to indicate on the map where assets where located, to draw the inundation extent they recalled and any other environmental aspects (such as native bush and sand dunes).

Tikanga was observed when undertaking interviews (2.3.1.4.2.1). A kaumātua (Māori elder; the interviewee's father, uncle or grandfather) who knew and had a pre-existing relationship with the key informant, attended the interview, and knowledge will be shared back with the participant. A copy of this thesis and any resultant reports and scientific papers will be shared with the Tangata Whenua involved in the research, and if possible, the author would prefer to do this in person to show respect (Kanohi Kitea - the seen face - present yourself to people face to face).

Three Tangata Whenua volunteered to take part in the research. All had experienced tsunami first-hand, and one remembered stories passed down from the grandparents' generation. The inundation extents and impacts collated from the interview were posted back to the participants for review. Two participants revised their inundation extents and added information to the impacts at this stage.

3.3.3 Collating Information from Documented Accounts and Tangata Whenua Knowledge

Information gathered from documented accounts and Tangata Whenua knowledge was combined in an Excel™ spreadsheet. Impacts were organised by theme: social impacts and experiences, environmental impacts, economic impacts and impacts on buildings and infrastructure. Impacts were also categorised by locality. Independent references (of supporting evidence found in documented accounts and oral history) are provided for each impact in Table 10, thus some quality assurance is provided by the number of references provided for each account.

3.3.4 Inferring Inundation Extents

The built and natural environment (exposed assets) contemporary with the historical tsunami events was digitised as accurately as the investigation allowed using photographs, maps identified during the investigation of documented accounts and information provided by Tangata Whenua; this allowed the spatial digitising of buildings, infrastructure, vegetation and geomorphology present at the time of impact.

Inundation extents were then inferred through digitising maps drawn directly by Tangata Whenua and/or by identifying impacted assets, and digitising the inundation around the locations of these assets.

3.4 RESULTS

The collation of documented accounts across various media (online articles, published academic articles, national tsunami databases, newspapers, diaries, letters, photographs and paintings) provided a wealth of information on historical tsunami events (Table 3.1). Tangata Whenua provided valuable information around inundation extents, locating assets and clarifying information included in documented accounts. The information shared by the three Tangata Whenua was fairly consistent and provided more context to documented accounts.

Result highlights included:

- Further information on the number of Tupuangi Pā fatalities in 1868.
- Locating assets mentioned in documented accounts (identified by Tangata Whenua, photographs and paintings) that were inundated, to allow spatial evaluation of tsunami inundation.
- An inferred 1960 inundation extent for Waitangi, mapped by Tangata Whenua who witnessed the event.
- An inferred 1946 inundation extent for Taupeka, mapped by Tangata Whenua who witnessed the event.
- Identification and location of physical ruins from the 1924 tsunami.
- Impacts of the 1946 and 1960 events that had not previously been documented.

The results are presented below.

3.4.1 Summary of Historical Tsunami Impacts

Table 3.1. Summary of historical tsunami impacts on the Chatham Islands.

Year & Tsunami Intensity	Source Time Generated (CIST) Time of Impact (CIST) Tsunami Travel Time	Warning CI Tide at Time of Arrival No. of Inundating Waves Wave size Inundation Extent Duration of tsunami activity	Impacts				Location of Impact
			Social Impacts or Experiences	Environmental	Economic	Buildings and Infrastructure	
1868 **IV-X**	Distant Southern Peru Mw 8.5-9.5 August 14, 10:15, August 15, 01:00, 15 hours (GNS Science, 2014)	On the 14th, the tide was abnormally low and a roaring noise was heard with the incoming waves (Details of the Earthquake Wave, 1868). Tsunami arrived approximately 1 hour prior to high tide (GNS Science, 2014). 3 inundating waves approached from the northeast. 10 minutes between 1st and 2nd wave, 3-5 minutes between 2nd and 3rd waves (GNS Science, 2014). The eastern and northern coasts were impacted before the western coastline was (Hawkes Bay Herald, 1868 as cited by Richards, Carter & Amery, 2009). Owenga: 10 m run up. Eastern coast and North West: 6 m inferred amplitude. Waitangi and South Coast: 2.4-4.6 m inferred amplitude (GNS Science, 2014). Inundation 6.4km inland in north-western part of the Island (De Lange & McSaveney, 2006). Abnormal surges and tides for following 24 hours, sea would rise 1 m above MHW over 15 minutes then remain static for 10 minutes before gradually retreating (Ritchie, 1868 as cited by GNS Science, 2014).	Some people in Waitangi had frightening experiences, Mr George Selwood's family were lucky to escape from a window in their house as the tsunami inundated their home and barricaded doors with furniture (Hawkes Bay Herald, 1868 as cited by Richards, Carter & Amery, 2009). The urupa at Waitangi Pa, near the river was scoured, possibly during this event or another big flood (key informant B).	It was thought that Tikitiki point absorbed or diverted some of the wave energy away from the township (Hawkes Bay Herald, 1868 as cited by Richards, Amery & Carter, 2009). Waitangi Beach was littered in house debris, timber, seaweed and stores such as flour and sugar (Earthquake Wave, 1868; Arrival of the Schooner Rifleman, 1868; The Late Tidal, 1868).	Residents, shop and hotel owners at Waitangi lost property and income (Arrival of the schooner Rifleman, 1868). Government stores including tonnes of flour were scattered over Waitangi Beach (Arrival of the Schooner Rifleman, 1868).	At least 6 buildings along the beach and river were inundated (Mr William Beamish's accommodation house, Mr Beamish's home, James Child Smithy's house, Mr Auckland's house, Mr G Taylor's house and Whares at Waitangi Pa), some were lifted off their bearers and badly damaged, in other houses possessions and stores were ruined. Waitangi Pa was badly damaged - several whare may have been destroyed. A newly constructed bridge over the Nairn River was washed away. A fence line was washed away. A shipwreck (the Florence) was washed ashore. (Arrival of the Schooner Rifleman, 1868; Important from the Chatham Islands, 1868; Details of the Earthquake Wave, 1868; Dunedin, 1868; Earthquake Wave, 1868; The Earthquake Wave; Travers, 1871; Jumping Claims, 1895; Richards, Carter & Amery, 2009; GNS Science, 2014).	Waitangi
			Unknown	Unknown	Unknown	Five whale boats were washed away (Hawkes Bay Herald, 27 October 1868 as cited by Richards and Carter, 2009). A few whare (houses) located 9 m above sea level were destroyed (Earthquake Wave, 1868). Some reports say Owenga was impacted similarly to Tupuangi (Hawkes Bay Herald, 1868 as cited by Richards, Carter & Amery, 2009).	Owenga
			Unknown	Unknown	Unknown	One boat was lost (The Late Tidal, 1868). Kaingaroa Pa was located on the opposite side of the harbour on high ground in early times, so may have escaped impact from the tsunami (Richards, 1972).	Kaingaroa
			Unknown	Unknown	Unknown	Huge spars were carried across the harbour and washed up high on a flat, but boats anchored in the bay were not affected (Important from the Chatham Islands, 1868; Dunedin, 1868; Earthquake Wave, 1868; The Earthquake Wave; 1868).	Port Hutt
			A diary records that 23 or 32 fatalities occurred at Tupuangi Pa, a village that was occupied by 60-70 people at the time (personal communication, 2016). Three large families were washed away with their houses, only some of their bodies were found and they were buried nearby Tupuangi on high ground (key informant B). The survivors evacuated to their old Pa site high on Mt Maunganui (The Late Tidal, 1868; Details of the Earthquake Wave, 1868). Tupuangi was then abandoned (Travers, 1871; De Lange & Healy, 1986).	Tupuangi Pa was cleared of vegetation, crops, village huts and then covered sand in seaweed (Dunedin, 1868; Earthquake Wave, 1868; The Earthquake Wave, 1868; Arrival of the Schooner Rifleman, 1868). East of Tupuangi Point severe erosion occurred, remains of a chief were relocated to high ground (Holmes, 1993). Boulders weighing half-a-ton were transported a considerable distance inland (Important from the Chatham Islands, 1868; Details of the Earthquake Wave 1868; Arrival of the Schooner Rifleman, 1868).	The people at Tupuangi Pa lost all of their possessions and crops (Dunedin, 1868). They had sold most of their stock before the event with intention to relocate back to Taranaki but lost £200 to £300 cash in the tsunami (Details of the Earthquake Wave, 1868).	All traces of inhabitancy at Tupuangi were destroyed (Arrival of the Schooner Rifleman, 1868). Whares would have been made from Kopi timber, ponga or parts of shipwrecks and they may have had ponga fences (key informant B). Two European houses (Details of the Earthquake Wave, 1868; Collins, 2005), one owned by Mr Engst (The Late Tidal, 1868), at Tupuangi were destroyed (Details of the Earthquake Wave, 1868; H. Bint, personal communication, February 3, 2018). Drays (horse carts) were destroyed (Important from the Chatham Islands, 1868).	Tupuangi
			A man named Makare drowned while trying to save a fishing boat between waves (Earthquake Wave, 1868; Arrival of the Schooner Rifleman, 1868; Holmes, 1993).	Unknown	Houses, belongings, livestock, cash, and stores were washed away and grazing land was covered in sand and seaweed (Dunedin, 1868; Earthquake Wave, 1868)	One or Two homesteads were destroyed at Te Raki, one belonging to Mr Hay (Dunedin, 1868; Earthquake Wave, 1868; Details of the Earthquake Wave; 1868; Holmes, 1906-2001a; Richards, Carter & Amery, 2009; Kain, 2011). The chimney is all that remains of the house and still stands today, cutlery was found wedged between the bricks (personal communication, S. Thomas, November, 2016). Captain Anderson's house at Waitangi West was also damaged (Arrival of the Schooner Rifleman, 1868).	Te Raki & Waitangi West
			Unknown	Erosion of sand accumulations (assumed to be sand hills or sand banks) along beaches on Pitt Island had caused a "great number" of slips in the hills above (Travers 1871).	Unknown	Unknown	Pitt Island
			400 Maori returned to their ancestral lands in Taranaki after this event, this was due to several influences including homesickness, a measles epidemic and the tsunami (Great Tidal Wave, 1914; Dennison, 1977; Holmes, 1984; Holmes, 1993; Lawrie & Powell, 2006). The Chatham Islands population was then reduced to 160 (Simpson, 1950).	Stout old akeakes (native tree) were broken like matchwood and debris were scattered far away (Post-Office Napier, 1877). Sand hills along the eastern and northern coasts were scoured, sand banks up to 6 m inland were eroded to beach level (Ritchie, 1868 as cited by GNS Science, 2014). Other areas (not specified) were also eroded and continued to erode for years following (Travers, 1871).	Loss of property and income, some residents were only left with the clothes they had on (Details of the Earthquake Wave, 1868). The tsunami stripped vegetation along the coast initiating sand blows, "thousands of acres of the best land were covered over," government assistance was required during early 1900s to restore the land for grazing and crops (Pupils of Kairakau School, 1939, p.167).	Damage was not recoded for Maori populations that may have existed along the eastern coastline (such as Te Awapatiki, Taia, Hapupu, or Waikeri) or along the South Coast (Richards, 1972).	Other

Year & Tsunami Intensity	Source Time Generated (CIST) Time of Impact (CIST) Tsunami Travel Time	Warning CI Tide at Time of Arrival No. of Inundating Waves Wave size Inundation Extent Duration of tsunami activity	Impacts				Location of Impact
			Social Impacts or Experiences	Environmental	Economic	Buildings and Infrastructure	
1877 VIII	Distant Northern Chile Mw 8.8 May 10, 13:14 May 11, some time during the night (GNS Science, 2014)	Natural warnings unknown. Nearing high tide. Unknown no. of waves. Estimated 3-3.5 m above MSL. Inundation extent unknown. Duration of tsunami unknown. (GNS Science, 2014).	Unknown	Unknown	Unknown	The Waitangi bridge was washed away, and two houses were inundated - Old Jamie's and Mr Beamish's (Evening Post, 1877 as cited by GNS Science, 2014; GeoNet, n.d). The Schooner Agnes was lifted off her cradle during the tsunami and left high and dry on the beach (Imports, 1877)	Waitangi
1924 IV-IX	Local Unknown Source July 21, Unknown July 21, 19:15-22:25 (Destructive Tidal Wave, 1924;Tidal Wave at Chatham Islands, 1924; Mishap at the Chathams, 1924; Acting Secretary Telegram, 5 August 1924 as cited by GeoNet, n.d; GNS Science, 2014) A large landslide occurred at Mangere Island (Tidal Wave, 1924)	Roar from the sea provided time for people to run at Kaingaroa and Owenga (Mishap at the Chathams, 1924; A Close Call, 1924; Destructive Tidal Wave, 1924). High spring tide. No. of waves unknown. Waves reached up to 6 m above MHW. Inundation 100m inland along the eastern coast (Destructive Tidal Wave, 1924). Waves continued for 3 hours. (GNS Science, 2014)	Unknown	The tide was abnormally high in Waitangi and surged up the Nairn River (Holmes, 1993)	Unknown	It appears Waitangi was not damaged (Destructive Tidal Wave, 1924; GNS Science, 1924)	Waitangi
			Mr. S. Clough, was washed off his horse when riding along the beach, but managed to cling to some tussocks and survived (Caught by Tidal Wave, 1924; key informantD). The Cemetery at Manakau was partially washed away (Caught by Tidal Wave, 1924).	Unknown	Loss of crushing plant equipment and fishing equipment may have been expensive. Shortly after the tsunami the crushing plant shut down (key informant B).	Machinery at the Owenga shell crushing plant (located at Shelly Beach) was damaged as it was washed out to sea but was washed back in again (GeoNet, n.d; Caught by Tidal Wave, 1924). A Hut used for the crushing plant was also inundated (GeoNet, n.d). Five dinghies were destroyed and two fishing launches, one was being re-fitted onshore (Tangaroa) and the other (Three Sisters) broke off its mooring and was wrecked on the reef at the entrance of Owenga harbour (A Close Call, 1924; Tidal Wave at Chatham Islands, 1924).	Owenga
			Fisherman had terrifying experiences, they were playing cards in their huts before hearing a roar from the sea and when seeing an incoming wave fled up the hill before their huts were inundated (Mishap at the Chathams, 1924; Caught by Tidal Wave, 1924; Tidal Wave, 1924).	Following the tsunami, the Rama, formerly the H.M.S Torch was wrecked after hitting an unchartered rock outside Kaingaroa. The Captain was an experienced sailor and knew the Chathams marine environment well, local fisherman were also unaware of the rock. The most recent survey at that time was from 1868 and there was speculation that the recent tsunami may have displaced rocks (The Rama Wrecked, 1924; Wreck of the Rama, 1924) .	It was estimated that it would have cost a considerable sum to rebuild the dam and that the company (Kaingaroa Fishing Co.) would not be able to continue fishing operations until the dam was rebuilt (Mishap at the Chathams, 1924; Tidal Wave, 1924; Caught by Tidal Wave; 1924; Destructive Tidal Wave, 1924)	Fisherman's huts were destroyed (A Close Call, 1924; Caught by Tidal Wave, 1924). A dam that supplied freshwater to Kaingaroa Freezer Works Company was inundated and scoured, as a result Kaingaroa Lake drained. (Tidal Wave at Chatham Islands, 1924; GeoNet, n.d; Tidal Wave, 1924; Destructive Tidal Wave, 1924). There was damage to the freezing works (A Close Call, 1924). Pipes to the freezer works were in pieces and offal troughs were washed away (Tidal Wave at Chatham Islands, 1924). No dinghy was left whole and a fishing launch sunk on her mooring while another launch (the Wahine) was lost, her rudder was found in the lake (Holmes, 1993; A Close Call, 1924; Tidal Wave at the Chatham Islands).	Kaingaroa
			Unknown	Beaches on Pitt Island were striped of shells (Mishap at the Chathams, 1924; GeoNet, n.d)	Unknown	Pitt Island wharf was completely destroyed and a dinghy and a surf boat were washed 70 meters up a creek (Mishap at the Chathams, 1924; GeoNet, n.d; (Destructive Tidal Wave, 1924; A Close Call, 1924; Holmes, 1993; key informant B). The creek referred to was in Flower Pott, it used to be quite deep (key informant A and B). The tsunami inundated ¾ of the way up to the Flower Pott house, and eroded the bank, also eroding and a big natural rock archway formation in the Bay.	Pitt Island
			Sailors and passengers aboard the Steamer Tees on Voyage from Lyttleton to Chathams also had terrifying experiences. When offshore (possibly 160km offshore) the Chathams on the 21st July at 9.30pm, the steamer was hit by the tsunami and caused the ship to kneel over, water flooded the engine room and a high pressure cylinder cracked. The boat was blown (possibly 160km) off course and took 4.5 days to reach Waitangi (Caught by Tidal Wave; Destructive Tidal Wave, 1924)	In the following 48 hours of the tsunami the sea was the roughest locals had seen it in 25 years (A Close Call, 1924). Pumice came ashore (Wreck of the Rama, 1924).	Unknown	At Wharekauri a bridge was badly damaged (Okahu) and fences were washed away (Caught by Tidal Wave, 1924; GeoNet, n.d; Holmes, 1993).	Other

Year & Tsunami Intensity	Source Time Generated (CIST) Time of Impact (CIST) Tsunami Travel Time	Warning CI Tide at Time of Arrival No. of Inundating Waves Wave size Inundation Extent Duration of tsunami activity	Impacts				Location of Impact
			Social Impacts or Experiences	Environmental	Economic	Buildings and Infrastructure	
1946 VI	Distant Aleutian Islands Mw 8.1 April 2, 01:13 April 2, Just before dark (GNS Science, 2014; key informant A).	The water retreated then a roar was heard before a wall of water came into the bay (key informant A; Collins, 2005). Unknown tide. Unknown no. of waves. Unknown wave height. Inundated Taupeka Point and paddocks around the house (key informant A). Unknown tsunami duration.	The mother of the family managed to call out to her children (with a stock whip) and directed them to their woolshed on higher ground before the tsunami inundated the house, she had experienced the 1924 tsunami (Collins, 2005). The Family then lived in the Woolshed until they rebuilt using parts of the old house and ponga (key informant A; Collins, 2005).	Pumice, kelp, and shells (paua and pipi) covered the paddocks and through the bush. Kauri logs washed up and were left in the creek (key informant A). Later when new fences were built and the land owners were putting fence posts in they noticed kelp and pumice under the surface soil (anonymous, personal communication, November 2016). Pumice can still be found in the paddock today (direct observation by author).	Unknown	The old Taupeka house was inundated and the out shed/workshop washed away. Later the house was pulled down and rebuilt further inland (where it currently stands) (key informant A; Collins, 2005).	Taupeka
1947 V-VIII	Regional Offshore Poverty Bay Mw 7.0-7.1 March 26, 09:17 March 26, 11:30 (GNS Science, 2014).	Unknown	Unknown	Unknown	Unknown	A boat that was beached at the high tide mark was washed further up the beach by an abnormally large wave (DSIR Seismological Observatory files, 1947 as cited by Johnston et al., unpublished)	Unknown
1960 V-VII	Distant Chile Mw 9.4-9.6 May 23, 07:56 May 24, Tsunami activity recorded at 1am (Nelson Evening Mail 25 May 1960 as cited by Johnston et al., unpublished), 4am (key informant C) and a third wave occurred at 06:30 (Holmes, 1993) (GNS Science, 2014).	No official warning, the tide surged in then retreated out past the wharf before surging in again with more force (key informant A), the policeman rushed round and told everyone to move to high ground (key informant B). Low tide at 1am (GNS Science, 2014) Wave height 1.8 m (Waitangi) to over 3.6 m (Pitt Island) (GNS Science, 2014). A 2 m surge travelled up the Nairn River (Holmes, 1993) The tsunami refracted around Tikitiki Point and also come from the North down the beach meeting with a splash, sloshing around in the bay and surging up the river (key informant C & B). It didn't have the volume behind it to push it over the sand dunes (key informant B). The water would retreat for 20 minutes then would rush back in. This activity continued but got less intense over the following 2 days (key informant A & C). Abnormal tides were observed for 4 days following the event (key informant A).	People staying in the fisherman's hut woke up early in the morning to the sounds of fishing pots washing around and slapping water, the water came up and washed everything away from around the hut but didn't get inside (key informant A). There was an evacuation after the tsunami impacted the island, informed by radio, as officials estimated the tsunami would travel 600miles/hr (key informant C; Homes, 1993).	After the water surged up the river and inundated the paddocks at Maipito (key informant A, B & C), the water would drain out down the river and soured out the river entrance 'pretty deep' (key informant B). Water ponded in the paddocks for two days following the event (key informant C). Rubbish sitting at the bottom of the River was washed up into the paddock (key informant C), and debris were also washed down the river (Holmes, 1993). The tsunami eroded a gap in the sand hill in Waitangi (near the current mechanic shop). The gap was then made into a crossing for horse drays to get down to the beach and at low tide they could cross at Te Kooti's cutting to get to the pub (key informant B). Sand from the sand dune in Waitangi was used to rebuild scour around the river and in front of the hotel (key informant B).	Abnormal and strong currents prevented fisherman from fishing for 3-4 days (key informant A). The Maipito farmer lost some stock as a few sheep drowned (key informant B).	Three boats at Waitangi sat on the bottom when the sea retreated, no damage occurred to the boats (key informant A). The tsunami washed away the ponga sea wall in front of the hotel and washed up against the hotel windows. Hours were spent cleaning kelp from behind the building, but the hotel stayed open that day (key informant C; key informant B). The tsunami washed around the fisherman's hut and it was later pulled down (kaumātua, C; key informant B). The wharf was not damaged but the water squirted up between planks of wood in the deck like steam (key informant A; key informant C) and lots of kelp was washed over the wharf (Holmes, 1993). There was minor damage to the old Waitangi Bridge, the river bank and one side of the foundations was scoured (key informant A; key informant C). A punt washed up from the river into the paddock at Maipito (key informant C). There was minor damage to the Nairn River house but everyone helped clean up (key informant B; R. Holmes as cited by Johnston et al., unpublished). The tsunami inundated a house (near the current factory) but nobody was in the house at he time. The residents shifted to another house near Maipito after the event (key informant B). A small school bus parked near the river may have been shifted from its original position by the tsunami (key informant B).	Waitangi
			Unknown	Unknown	Unknown	At Okawa, kelp was washed up onto the paddock and a fence was washed 150 m inland from the 1960 coastline (George Hough, as cited by Johnston et al., unpublished; Kain, 2011). At Waitangi West, the tide was around 2 m higher than usual and inundated up to 120 m inland. A stone wall was flattened and fences were washed away (Mr R. D. Cannon, The Press (Christchurch) 25 May 1960 as cited by GNS Science, 2014]. The tide was approximately 3.6 m above normal at Pitt Island, a dingy was washed away and the wharf was damaged [J. Moffet, The Press (Christchurch) 25 May 1960 as cited by GNS Science, 2014]. Fisherman offshore the east coast of Pitt Island and at Owenga did not observe anything unusual [The Press (Christchurch) 25 May 1960 as cited by GNS Science, 2014]. Damage at Owenga and Kaingaroa was not recalled (key informant A, B, C).	Other

3.4.2 Inundation Extents of Historical Tsunami

3.4.2.1 1868

The 1868 event inundated the majority of the Chatham Islands coastline with the eastern coasts and north-western point (Tupuangi to Te Raki) experiencing the most inundation and worst impacts (Table 3.1; Figure 3.2). The tsunami inundated up to four miles (6.4 km) inland around Tupuangi (McSaveney, 2006). The regional inundation map was generated by geo-referencing Thomas Ritchie's (a local run holder at the time) map of inundation (Appendix E.1, Figure E.1).

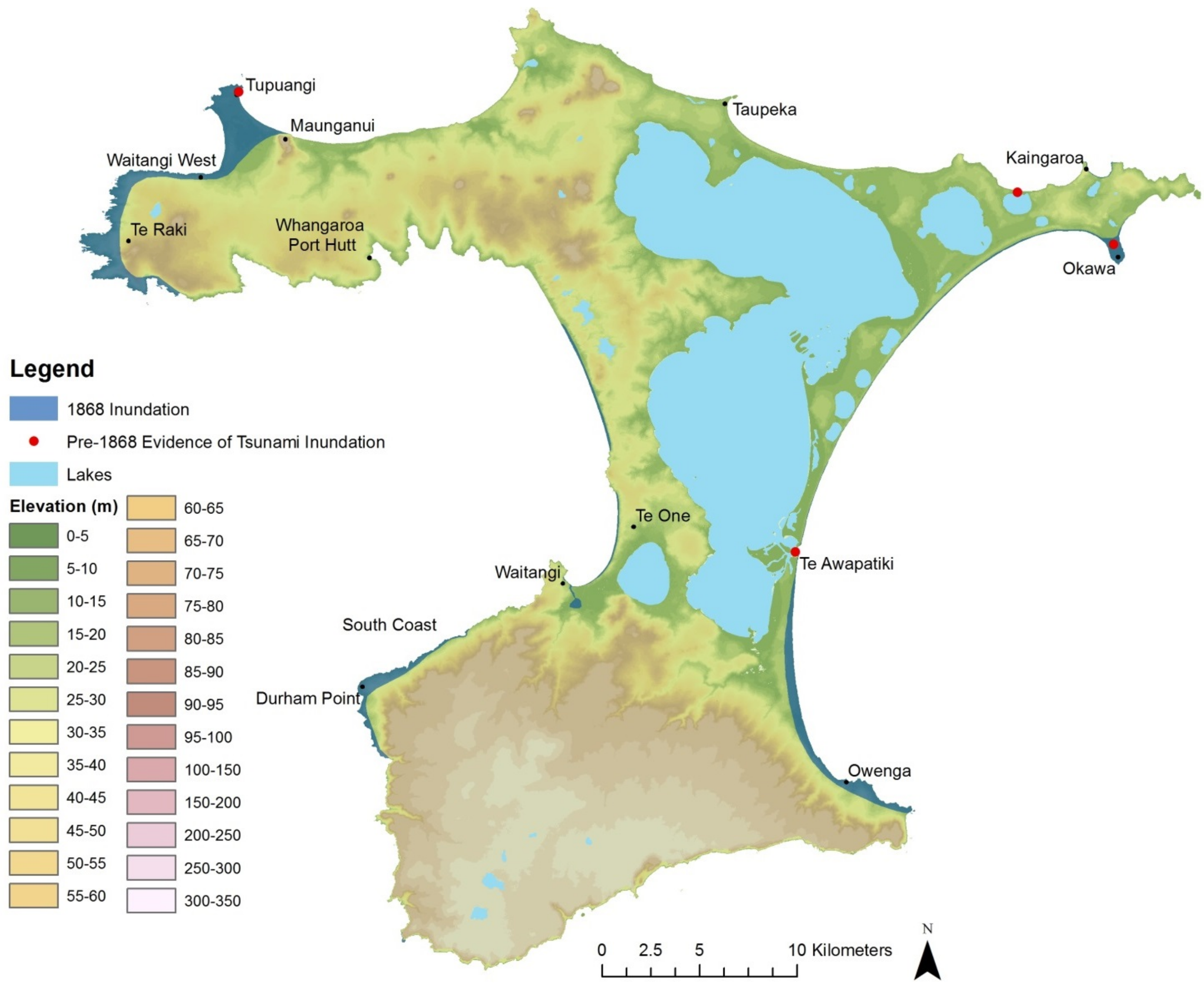

Figure 3.2. Inundation of the 1868 event in the Chatham Islands. Locations of Pre-1868 evidence of tsunami inundation were sourced from McFadgen, (1994), Goff et al., (2010), Nichol et al., (2010), and the New Zealand Palaeo-tsunami Database, (2017). Chatham Islands data retrieved from NIWA (DEM) and LINZ (waterbodies).

3.4.2.1.1 Inferred 1868 inundation extent for Waitangi

An inferred inundation extent for Waitangi was informed by well-documented accounts for the main township. Inundation extents could not be generated in closer detail for other settlements such as Owenga and Kaingaroa due to insufficient information.

Documented accounts for Waitangi provided clues such as “the Pā on low-lying land suffered considerably” (Jumping Claims, 1895), “of the picturesque bridge recently erected not a timber remains” (Hawkes Bay Herald, 1868 as cited by Richards et al., 2009), and Mr Beamish’s accommodation house was lifted off its bearers but Mangouts Hotel (located next door) was unscathed (Hawkes Bay Herald, 1868 as cited by Richards et al., 2009). These clues and the photos used to locate buildings that existed in 1868 (Appendix E.1) allowed an inundation extent to be inferred. Of interest is Figure 3.3. The painting illustrates buildings being inundated by the 1868 tsunami with debris floating in the water; the painting is in a book of Chatham Islands history written by Kairakau School (a school on the Chatham Islands that is now closed) students. The painting was an illustration from the book compiler (one of the ex-students that contributed to the book) and may be imagination of the impacts. This could be interpreted as being a scene from Waitangi, indicated by the red bluff in the background.

Figure 3.3. Buildings inundated by the 1868 tsunami, possibly in Waitangi (Red bluff in the background). Retrieved from Pupils of Kairakau School (1939, p.167).

Tangata Whenua did not recall inundation extents for Waitangi but were able to assist with verifying locations of buildings and infrastructure mentioned in documented accounts, as well as providing information on the environment at the time. This included locations of houses, the Waitangi Pā/kainga, track (before roads were built), the old bridge location and where native bush used to exist. Key informant B reported that the urupā (burial ground) at Waitangi was scoured during an inundation event or over several events (could be by floods, storm surge or tsunami). The location of the urupā and the area that was scoured were mapped by key informant A and included in Figure 3.4. Documented accounts record major erosion during this event, and scour around the river during this event is possible. Tangata Whenua also revealed that a substantial sand dune used to exist in Waitangi which extended from the east to the A-Frame house (located at the end of the sand in Figure 3.4). The sand dune has since been removed to reclaim land around the hotel and has also eroded. Today, the sand dune starts near the mechanic shop – outside the eastern extent of Figure 3.4 (key informant B, local knowledge).

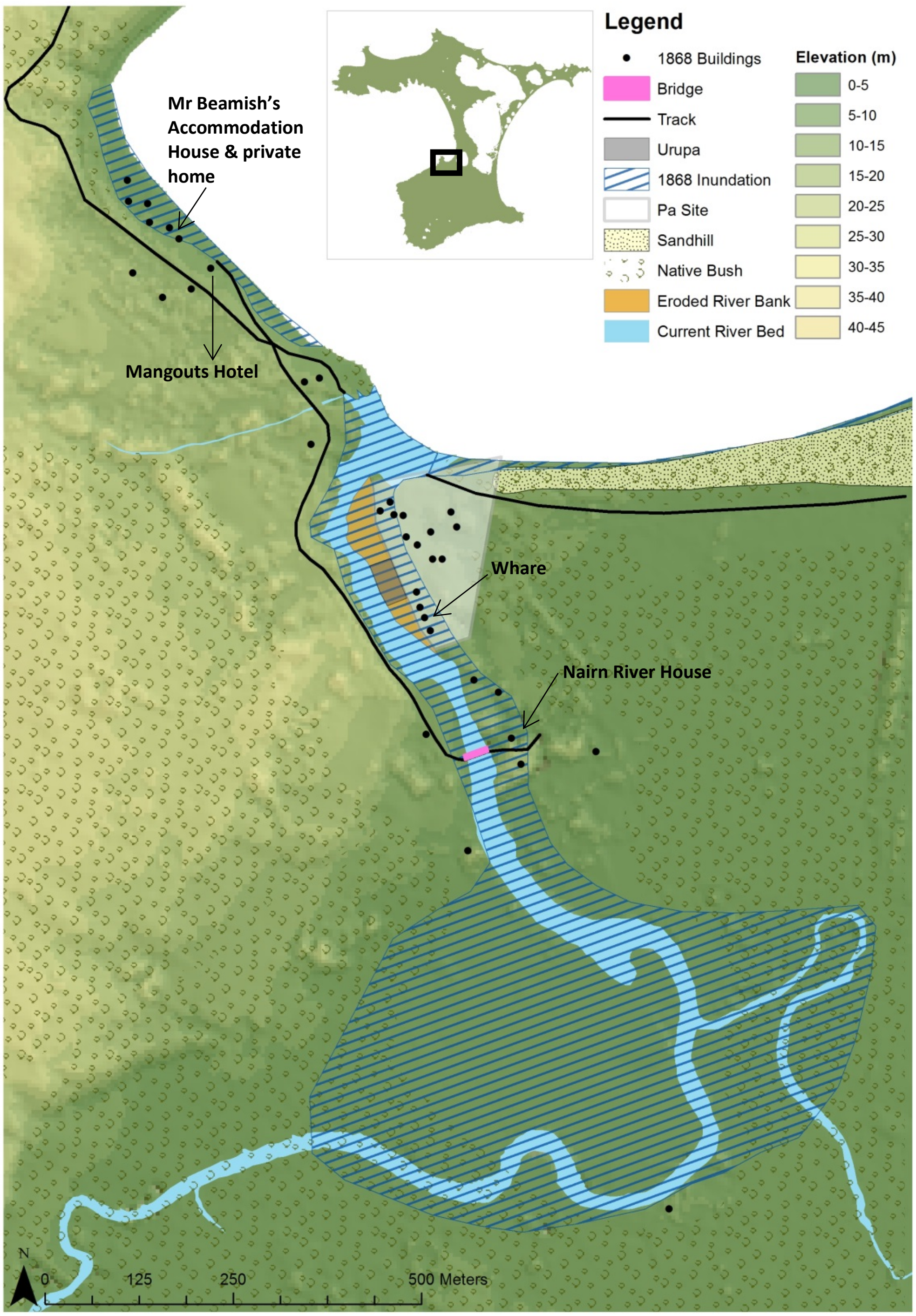

Figure 3.4. Inferred 1868 inundation extent for Waitangi. Chatham Islands data retrieved from NIWA (DEM) and LINZ (rivers).

3.4.2.1.2 Inferred 1868 inundation extent for Waitangi West

The north-western part of the Island was worst impacted and experienced the greatest inundation extent (Ritchie, 1868 as cited by GNS Science, 2014; Dunedin, 1868; Earthquake Wave, 1868; Details of the Earthquake Wave; 1868; Holmes, 1906-2001a; Richards, Carter & Amery, 2009). The inundation for this area was evaluated by geo-referencing Thomas Ritchie's inundation map and through documented accounts. Tracks were determined from an old survey map (Department of Lands and Survey N.Z., n.d) and two ruins caused by the 1868 tsunami verified inundation at Te Raki (Kain, 2011; Richards et al., 2009) and Tupuangi (Goff et al., 2010). The Pā site location was inferred using the location of the name Tupuangi on maps and the old track location. The track makes a loop around an area, this is inferred to be around the Pa. The house ruin is located within this loop (Figure 3.5).

Tangata Whenua provided information on the number of fatalities that occurred at Tupuangi. Key informant B remembers being told by his father (when he was young) that three families were washed away with their houses at Tupuangi. These were big families, as key informant B indicated Māori had lots of children in those days. The event occurred before his father's time but his father was shown where other community members buried the bodies they found. Key informant B was told the names of these people but could not recall them. Oral history also revealed that the western side of the cape used to be a whaling harbour before it 'sanded up', developed soil and grew vegetation.

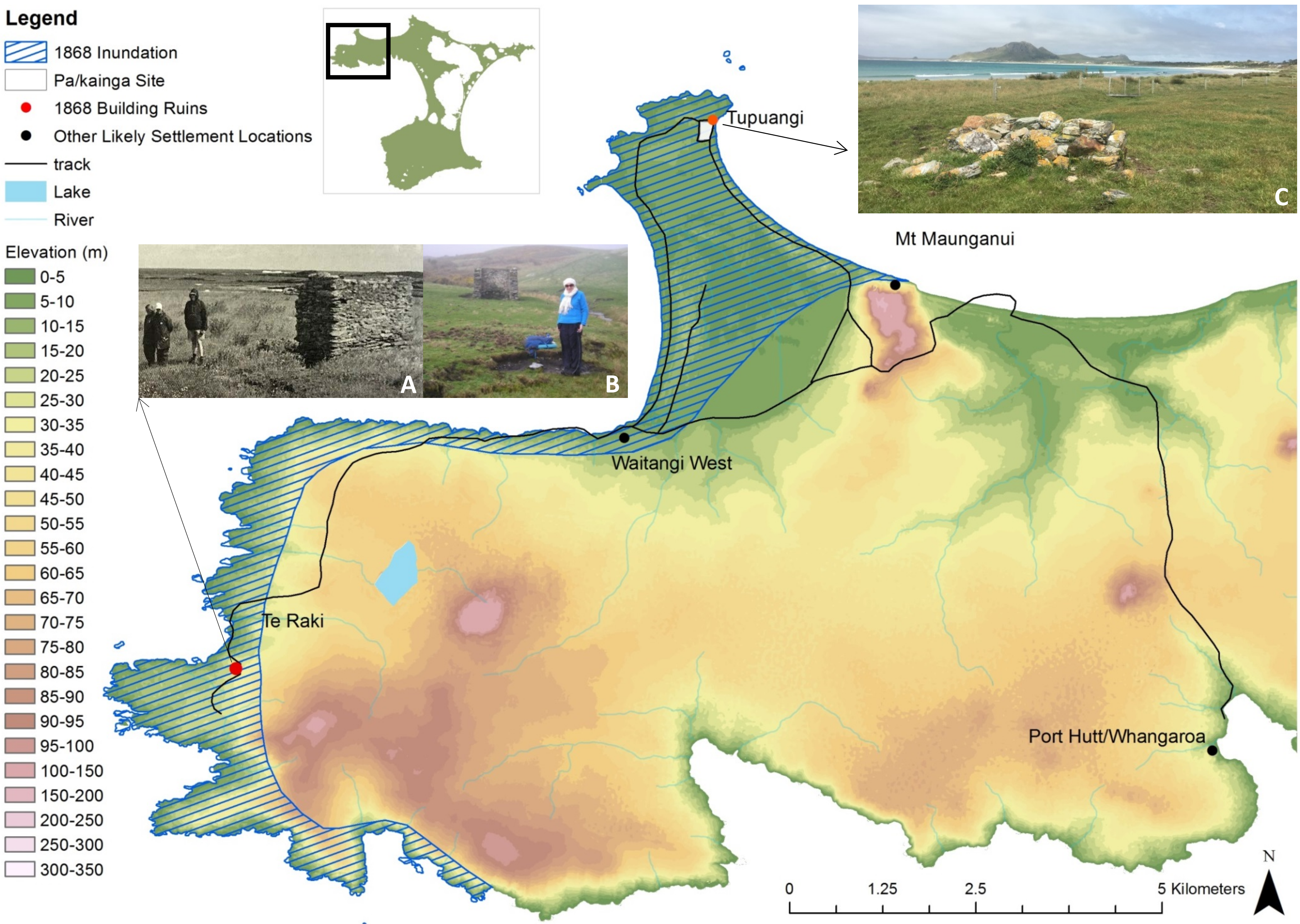

Figure 3.5. Inferred 1868 inundation extent in the north-west of the Island. Photo A: remains of Thomas Hay's homestead at Te Raki, retrieved from Richards Amery & Carter, (2009, p.98). Photo B: the same ruin, or another at Te Raki, retrieved from Kain, (2011, p.9). Photo C: house ruin at Tupuangi taken by the author. Data retrieved from NIWA (DEM).

3.4.2.2 1924

Inundation during the 1924 event was recorded at Kaingaroa, Owenga and Flower Pott (Pitt Island), and a landslide also occurred at Mangare Island. Ruins of the factory pipes were located by the author, and key informant C clarified that these may have been intake pipes for the factory (Appendix E.1, Figure E.14). Tangata Whenua recalled some inundation extents such as “3/4 of the way to the Flower Pott house” and were able to clarify locations of impacts and further detail around the buildings and infrastructure impacted.

Inundation extents are provided for Owenga (Figure 3.6) and Kaingaroa (Figure 3.7). Pitt Island was not included due to limited information on areas that were inundated, apart from one creek. Key informant B identified that Kaingaroa harbour had been eroded over time through big storms and tsunami, and the old shore line was ‘quite a bit further than where it is now’. Key informant A also explained that Fisherman’s huts used to exist on the seaward side of the road, and people used to have picnics on big grassy areas, all of which have since eroded away. The fisherman’s huts on the seaward side of the road and area of land that used to exist were visible in a photograph of Kaingaroa harbour taken in 1947. The photograph was used to digitise the eroded land extent (Appendix E.1, Figure E.13).

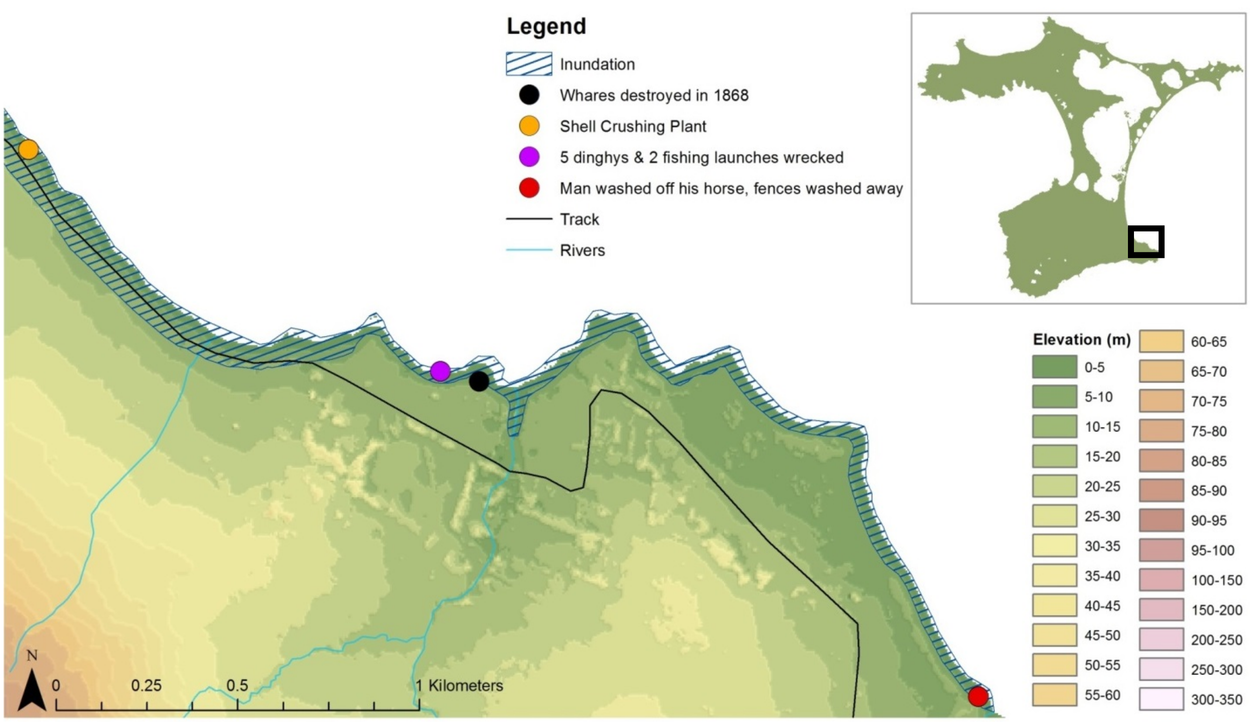

Figure 3.6. Inferred 1924 inundation in Owenga. Chatham Islands data retrieved from NIWA (DEM) and LINZ (waterbodies).

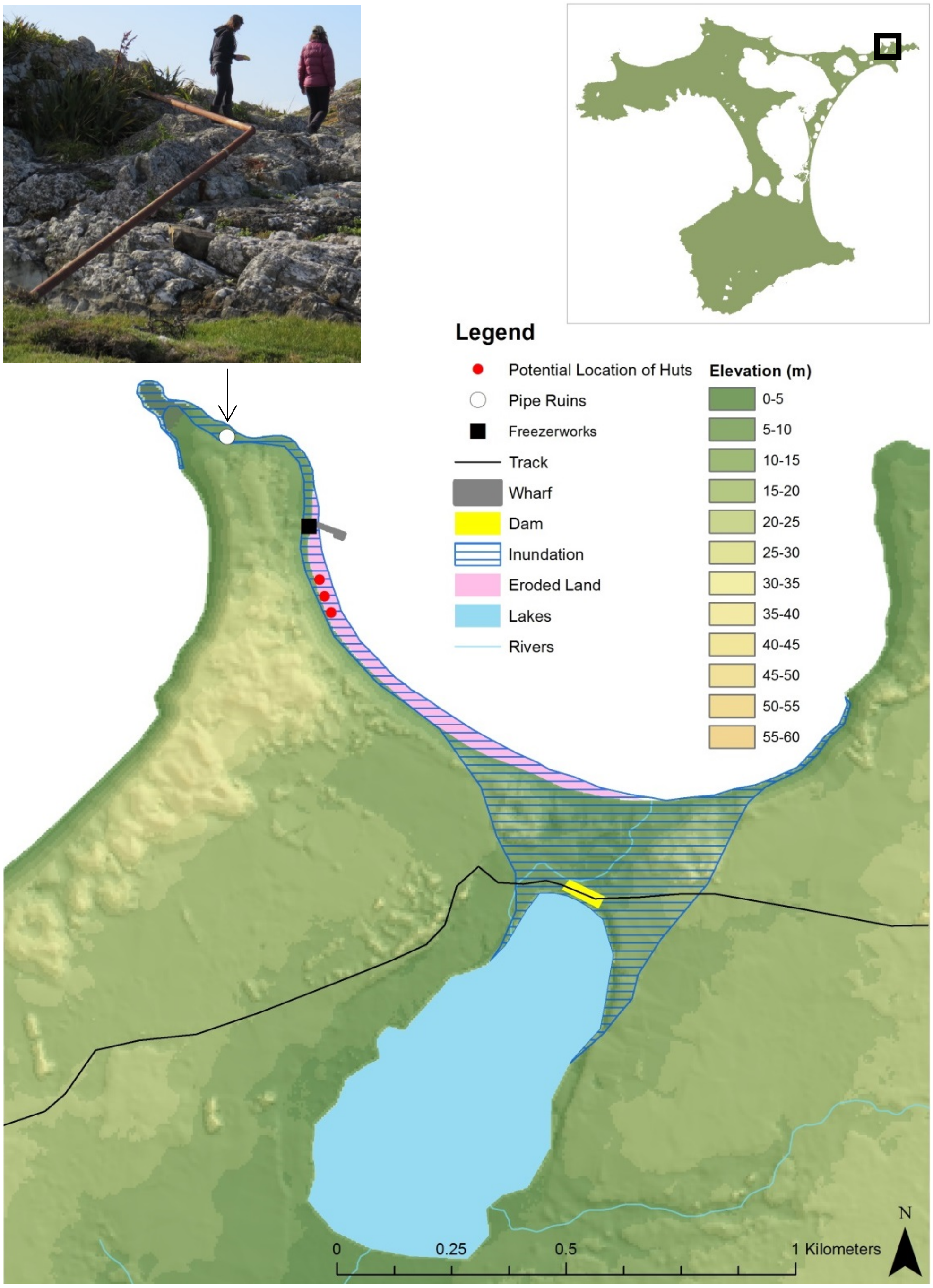

Figure 3.8. Inferred 1924 inundation extent for Kaingaroa. Chatham Islands data retrieved from NIWA (DEM) and LINZ (waterbodies). Top Left photograph of the freezerwork intake pipes ruined by the tsunami (Kate Crowley).

Boats in Kaingaroa were also damaged (Table 3.1), but the location of these was not determined. Mapping of eroded land was informed by Tangata Whenua.

3.4.2.3 1946

Before this investigation the only information known about the impacts of the 1946 tsunami on the Chatham Islands was from Collins (2007). Accounts of a house being inundated and damaged were given by a witness who was 10 years old at the time of the event. This recollection states that the event occurred in 1947. However, as GNS Science (2014) indicated the 1947 Gisborne tsunami are not known to have generated large waves at the Chatham Islands and, given the effects at Campbell Island in the 1946 event, it is more likely that the event described in Collins (2007) occurred in 1946. This is supported by key informant B in this study recalling that the tsunami that impacted Taupeka came from overseas, possibly Chile.

Tangata Whenua provided a detailed account of the environment at the time of the event, the inundation extent and impacts as included in Table 3.1. The area was significantly more covered in native bush than today and part of a substantial sand dune has since eroded (Figure 3.9). The current fence line has been shifted back several meters by the land owners due to coastal erosion. Evidence of this inundation extent was also provided by people who helped put in the present fence line. Locals noted pumice and kelp under the surface when putting in fence posts.

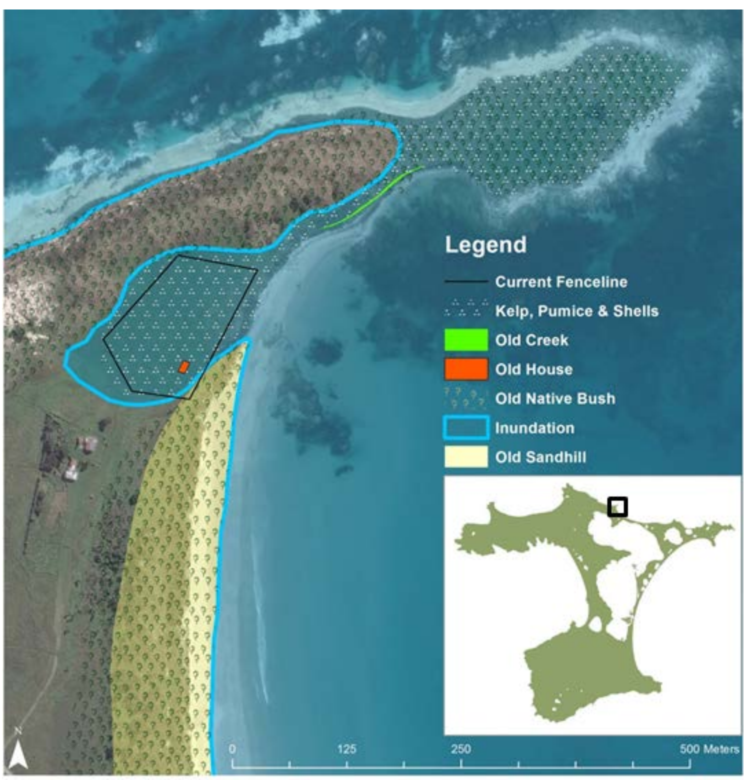

Figure 3.9. Inferred 1946 inundation in Taupeka. Data retrieved from Google Earth (2015 Imagery), NIWA (DEM).

3.4.2.4 1960

Tangata Whenua mapped inundation they recalled from witnessing the 1960 event (Key informants would have been in their 20s at the time). Although the extents mapped by individuals are slightly different, they all show that the tsunami was mostly contained within the river banks until near the Maipito woolshed where it overtopped the river banks and inundated the paddocks. Tangata Whenua knowledge, photographs (Appendix D.1) and an old survey map (Lands and Survey N.Z., n.d) were used to locate impacted buildings and infrastructure. The Waitangi sand hill still existed in 1960, although the tsunami scoured one section of the dune (near the current mechanic shop, indicated by the inundation into the sand hill in Figure 3.10) and this was later made into a track down to the beach.

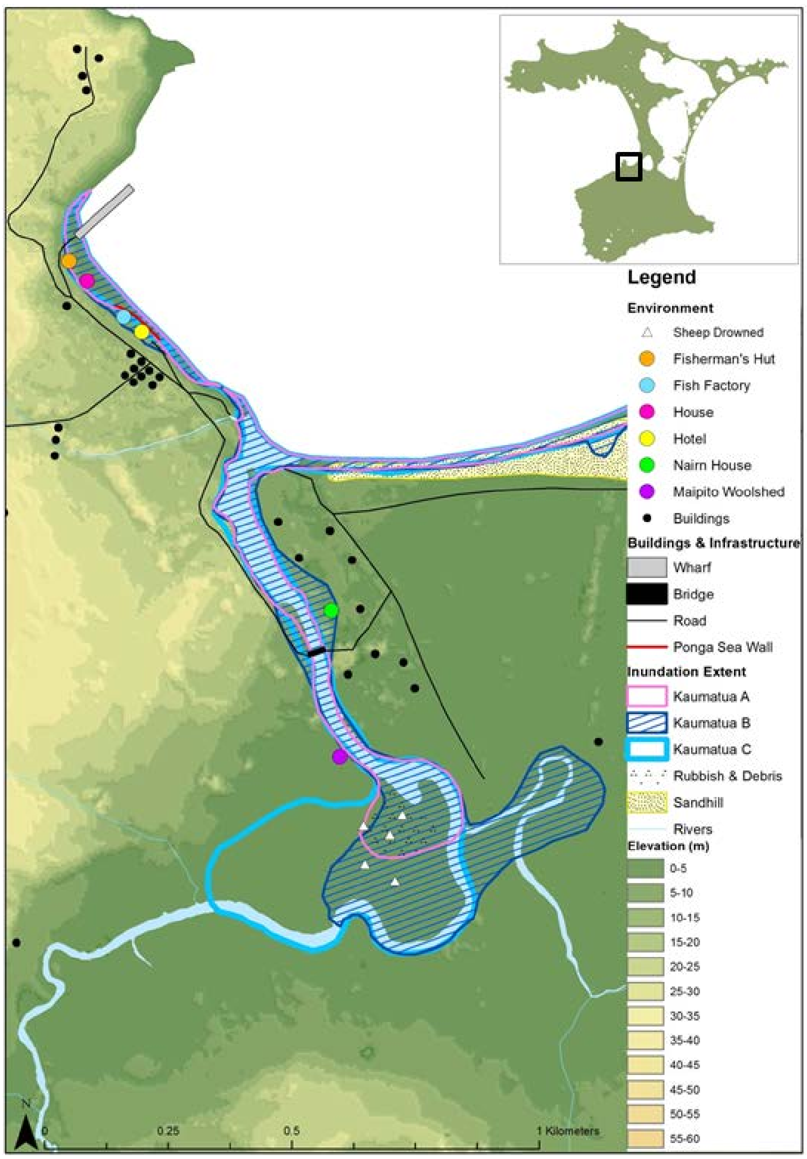

Figure 3.10. 1960 Inundation extents in Waitangi. Chatham Islands data retrieved from NIWA (DEM) and LINZ (waterbodies).

3.5 DISCUSSION

3.5.1 Methodology

Combining sources of information from documented accounts and Tangata Whenua knowledge was an effective methodology for exploring historical tsunami impacts and inundation extents. Documented accounts of tsunami were researched and collated before interviewing Tangata Whenua of the Chatham Islands. This provided the interviewer with a base understanding of impacts that occurred during each tsunami, and of important events that occurred around the time of the event. This understanding allowed prompts to be made with linkages and references to impacts that occurred or unrelated events that happened around similar times, allowing a deeper investigation of impacts and inundation extents. For example, the participants responded better to questions such as “do you remember the Kaingaroa dam that washed out during the cod boom days? What happened?” compared to “what do you remember of the 1924 tsunami?” Questions such as the former would initiate a domino effect of thoughts and recollections about those days, what the environment looked like back then, and brought memories of the event to light.

Researching documented accounts before undertaking semi-structured interviews also provided an opportunity to clarify material and locations, with Tangata Whenua filling in any gaps. Tangata Whenua have a wealth of knowledge around changes in the environment, old locations of buildings, where people lived and infrastructure assets, and so were very effective in providing clarification. The opportunity to ask Tangata Whenua questions about the documented accounts was a great asset in this study; often more information was shared when clarification questions were asked, and Tangata Whenua were also able to provide an indication on the quality of the source of the documented accounts “I wouldn’t trust what that person said, they spoke a lot of rubbish in their day, and they didn’t even live here”.

Aerial photographs provided an effective tool for referring to locations and mapping inundation extents. However, because Tangata Whenua were not familiar with the aerial view of their environments, some time was given during interviews to assist Tangata Whenua in orientating themselves in the maps. This was not a substantial problem for documenting their experiences and knowledge, but future studies could try different viewpoints such as low-angle (drone photography) and eye-level photographs.

Being a local and having an existing relationship with the Tangata Whenua (either directly or through the author's relations) assisted in providing a relaxed and trusting environment (often where a few laughs were shared) for the conversation to occur and Tangata Whenua to share their knowledge. Local knowledge of the area and history also greatly assisted in both conversation flow and locating assets when the aerial maps were not an appropriate scale to reference "you know where the Ngaio tree used to be? That's where the hut was" "you know the ditch just before you go down to the beach? That's where the creek used to run."

The purpose of this research is to provide useful outcomes for the Chatham Island community, aimed to be achieved by including as much community participation in the project as possible (Section 1.3.4). This methodology allowed participation of Chatham Island community members in the research; Tangata Whenua shared information to be used in the research and were involved in the interpretation of the data and reviewed the results. Other Chatham Islanders were also involved in the research through helping the author search for documented accounts in all forms of archives and were most helpful.
Kaupapa Māori research principles were followed in this research; respectful research methods nurtured trust and, in turn, a wealth of information was shared with this study. However, "there is next to no research, no literature, no guidance to the issues which concern indigenous, minority group researchers, carrying out research within their own communities" (Smith, 1999, p.8). Local researchers undertaking indigenous research in their own communities risk their existing relationships with their communities, and risk the mana (respect) of their whānau if they do wrong, and thus are held to a greater level of accountability and transparency (Davidson & Tolich, 2003, p.47). Local researchers cannot just walk away from a project when it is done. This is a daunting prospect for any local researcher, let alone new researchers and students unfamiliar with indigenous methodologies. Having a network of indigenous experts and fellow students to call upon for advice was necessary, and being accompanied by a related kaumātua when undertaking interviews also provided support.

3.5.2 Tsunami Impacts

This study has produced a catalogue of Chatham Island tsunami impacts collated from documented accounts and Tangata Whenua knowledge. This catalogue (Table 10), provides more information than is currently included in National Databases (GNS Science, 2014; National Palaeo-tsunami Database, 2017) and provides a better understanding of historical tsunami impacts. Tangata Whenua provided more information on social, environmental, economic, building and infrastructure impacts for the events of

1868, 1924, 1946 and 1960 than is recorded in documented accounts. Of particular interest is the revised number of fatalities that occurred at Tupuangi kainga/Pā from 1 to 23 or 32 (Chatham Island resident, personal communication, November, 2016). Another important finding is uncertainty in the current documented date of the 1924 event.

3.5.2.1 Accounts of the 1868 Event

Tangata Whenua knowledge allowed a fuller understanding of the 1868 event's impacts than Thomas' (2017) investigation informed by documented accounts alone. The current number of historical tsunami fatalities in Aotearoa-New Zealand (A-NZ) is 1 – a Māori man named Makare who drowned while saving a fishing boat at Waitangi West, Chatham Islands in the 1868 event (Arrival of the Schooner Rifleman, 1868; Earthquake Wave at the Chatham Islands, 1868; Holmes, 1993; GNS Science, 2014; Table 10). However, as Thomas (2017) noted, the exact number of fatalities that occurred on the Chatham Islands is uncertain. Some reports state that several Māori were drowned while trying to save a boat, or that a few natives died (The Earthquake Wave, 1868; Great Destruction, 1868; De Lange and Healy, 1986). De Lange and Healy (1986) record that an occupant was swept away with their house, and later reports mention only one death, a pākehā.

Thomas (2017) was informed of a diary that records either 23 or 32 fatalities at Tupuangi (Chatham Island resident, personal communication, November, 2016). While the diary is yet to be found, the information is consistent with Tangata Whenua knowledge (key informant B), that three families were washed away with their houses during this event and documented accounts that refer to multiple fatalities (The Earthquake Wave, 1868; Great Destruction, 1868; De Lange and Healy, 1986). Māori families were large in those days, as parents had lots of children (around 10 or more). Three Māori families could easily equate to 23 or 32 people. Locating the diary would provide additional (written record) evidence, but the oral history recorded in this study should also be considered a legitimate source of information by academics.

There may have been several reasons why these fatalities were not recorded in other documented accounts;

- Death in the Te ao Māori is tapu (sacred) and appropriate Tikanga is involved in the mourning process. Losing multiple whānau would have been devastating. Tupuangi kāinga/Pā may have kept to themselves, mourning the loss of their loved ones and holding tangi (funeral), not broadcasting their losses to newspaper correspondents and pākehā (European people) who they did not know or necessarily trust.

- Tupuangi is relatively isolated from the rest of the Island; in the 1800s communication was slow. People would travel infrequently, only for events, business and for obtaining stores from the supply ship. The fatalities may not have been reported to others for weeks to months following the event. 400 Māori, including inhabitants of Tupuangi, left the Chathams shortly after the tsunami, for various reasons including homesickness for their ancestral lands, a measles epidemic and the tsunami (Great Tidal Wave, 1914; Dennison, 1977; Holmes, 1984; Holmes, 1993; Lawrie & Powell, 2006). The Chatham Islands population was then reduced to 160 (Simpson, 1950). The information on tsunami impacts including fatalities also may have gone with them.
- As Thomas (2017) noted, relationships between Māori and pākehā at the time may have contributed to the lack of information being passed on. Some pākehā were ill-disposed towards Māori at the time due to events involving Te Kooti (Māori leader, founder of the Ringatū religion and guerrilla fighter; Richards et al., 2009) and the Hau Hau prisoners. Other language in newspapers also suggest racist attitudes during these times; "These Māoris are now industriously farming, whereas, it seems only a short time ago we were teaching them civilisation," (Great Tidal Wave, 1914) “by a Māori, we are informed,” (Details of the Earthquake Wave, 1868) “the condition of the poor Māoris” (Post-Office Napier, 1877), “a few natives died” (The Earthquake Wave, 1868).
- 1868 was also generally an unpleasant year on the Chatham Islands. Approximately 50 people died from measles, land was confiscated from Māori, the brigantine *Express* was wrecked, Hau Hau prisoners were murdered and stole from inhabitants during their escape from the island, the tsunami occurred and a woman committed suicide (Richards and Carter, 2009). Thus accounts of the tsunami were often over-shadowed by other events recorded in books and diaries.
- Makere’s death was likely recorded as he died trying to save a pākehā’s (Captain Anderson’s) boat.

3.5.2.2 Accounts of the 1924 Event

The New Zealand tsunami database records the 1924 event occurring on the 19th of July based on accounts provided by Acting Secretary Telegram, (5 August 1924). However, newspapers (published 2-

4th of August) state the event occurred on the 21st of July (A close call, 1924; Caught by Tidal Wave, 1924; Destructive Tidal Wave, 1924; Tidal Wave at Chatham Islands, 1924; Tidal Wave; 1924; Mishap at the Chathams, 1924). Accounts also state “The eastern side of the island was found to have suffered from a tidal wave apparently about the same time as had the ship, and the people had feared the worst” (Caught by Tidal Wave, 1924). The ship “Tees” departed Lyttleton on the 19th (A close call, 1924; Caught by Tidal Wave, 1924), and this may be the source of confusion in the Telegram. The 21st July date has been included in this study’s results (Table 10).

Based on information that the tsunami occurred on the 19th July, and accounts of the ship encountering rough weather, GNS Science (2014) interpreted the near-capsizing of the ship as storm-related, not tsunami-related. Details of the voyage provided by the captain, recorded in newspapers, state the ship was making “good progress in a moderate sea” (A Close Call, 1924; Caught by Tidal Wave, 1924). Then, “without the slightest warning,” were suddenly struck by a big wave, the captain stating “there is not the slightest doubt that we had been struck by a tidal wave” (Caught by Tidal Wave, 1924; A Close Call, 1924). Experienced captains would have been familiar with sailing through storms; one could assume if the ship was struck by a storm, the captain would have stated this, instead he called it a tidal wave. Newspapers do record the weather growing worse during the night and the ship was “rolled and tossed in the heavy seas… and on the Tuesday [22nd July] the ship was put before the increasing gale” (Caught by Tidal Wave, 1924). The mainland also experienced ‘southerly weather’ on Monday the 21st (A Close Call, 1924). However, given that the captain did not mention the weather as being a factor in the wave that struck the ship, a tsunami causing the near-capsizing of the Tees should not be ruled out. Newspaper accounts state either that the Tees was approximately 160 km West of the Chatham Islands when the event occurred (Destructive Tidal Wave, 1924; Tidal Wave, 1924; Tidal Wave in Chathams, 1924; Mishap at the Chathams, 1924) or was blown off course 160 km due to engine damage (Caught by Tidal Wave, 1924; A Close Call; 1924). Future investigations could include calculating where the Tees may have been at the time of impact (based on travel time from Lyttleton Port) and determining whether a tsunami wave could have been of sufficient amplitude in this area to cause the described impacts. Tsunami waves generally have smaller amplitudes when travelling through open water far from shore (Power, 2013). However, the Chatham Rise, where the Tees would have been, is quite shallow (350-400 m depth) compared to off the flanks of the Chatham Rise (4000 m deep) (Mackay, Wood, & Clark, 2006).

3.5.3 Inundation Extents

Tangata Whenua knowledge and documented accounts have provided an improved and invaluable understanding of past inundation extents. Apart from Thomas Ritchie's 1868 inundation map (Appendix E.1 Figure, E.1), no other inundation extents of other events in populated areas had been investigated or inferred. Thus this study has improved understanding of tsunami hazard for the Chatham Islands.

Of interest are Tangata Whenua recollections of sand dunes and native bush that used to exist and have since eroded or depleted. The Waitangi sand dune appears to have protected low-lying land from being inundated in both the 1868 and 1960 events, the only inundation occurring around the river. The sand dune is now non-existent and the land behind is no longer protected from future tsunami inundation. This topic is explored further in Section 4.4.1.1.

Thomas (2017) discussed how accounts recording Mr Beamish's accommodation house in Waitangi being badly damaged, but Mongute's house (located next door) not, seemed dubious. However, this study revealed that similar highly localised impacts were observed in the 1960 event. The fisherman's hut and a house were inundated on the western side of the beach, yet the hotel (in the same location as Mangouts) experienced only had minor damage with kelp deposited around the building.

These inundation extents indicate locations that may record previous events in the sedimentary record. Future research could involve exploring sedimentary evidence of historical tsunami events in the areas oral history has indicated (King et al., 2017).

3.5.4 Limitations & Future Work

Documented accounts are limited by the accuracy of recall and truthfulness of storytellers or newspaper correspondents, by exaggeration due to relay-related distortion of information, and by personal perception or circumstances in diaries. While newspapers provide an account of events, these stories were mostly passed on through shipping crew and passengers sometimes weeks after the event, and not from residents or government correspondents. Place names were often spelled wrongly. Tangata Whenua knowledge provided some clarification of documented accounts but future reviews should compare sources of information to establish some criteria of credibility. As noted previously the number of references used to support each statement provides some idea of the popularity or wide awareness of the information. However, newspapers often repeated each other, providing more references for the same information, and were sourced from correspondents, or shipping staff visiting the Island for a limited time. Some form of weighting could be applied for locally-provided accounts, visitor-provided accounts, and the age of the account (days, weeks, months, years, decades following) to evaluate credibility of the information.

Tangata Whenua knowledge is also limited by human error and memory. These recollections and memories are from at least 58 years ago (1960 was the last inundating event). Tangata Whenua knowledge is also limited by where the participants were at the time of events. The three Tangata Whenua were all in Waitangi at the time of the 1960 event. Recollections from other Tangata Whenua or pakeha who were at other locations may provide more information for other areas of the coastline and in other settlements.

There are also limitations in locating exposed assets at the time of the tsunami events. Photographs were taken around the time of impact but sometimes not the same year, as were survey maps of buildings and infrastructure. Therefore, locations of asset locations are inferred. The location of 'James Child's smithy's house' in Waitangi remains unknown. The author was also informed of another painting were Maipito is undated, potentially during the 1868 or 1960 events or during a flood event. Future work could include locating this painting.

A diary located in the Alexander Turnbull Archive collection apparently holds the number of fatalities that occurred at Tupuangi during the 1868 event, supposedly either "23 or 32 people" (Chatham Islands resident, personal communication, 2016). This information was supported by key informant B and some documented accounts (Section 3.5.2.1). Finding the exact number of fatalities during this event is important as these are New Zealand's only recorded tsunami fatalities. Daily entries in diaries were searched for information on tsunami impacts, these were searched in entries made on the date of impact, and entries 14 days following impact. Reading the diary entries was time consuming due to old styles of handwriting which were difficult to read. Nothing was found about the 1868 tsunami fatalities. Communication in the Chatham Islands around the times of the 1868, 1924, and possibly 1946 events was limited to physically talking to someone. During these times it also took effort to travel to other settlements (a whole day on a horse) and people would only travel for specific reasons e.g. for an event or if the supply ship was coming in with stores. The diary of William Jacobs records that he only travelled to town days after the 1924 tsunami, and the only mention of the event was the delay in the arrival of the schooner Rifleman (Jacobs, 1924). By the time people got into town, other news was more prevalent. Other personal diaries that record tsunami details (including the diary of Thomas Ritchie and papers of Holmes) have missing pages for the year 1868. It is also noted that the published copy of Chudleigh's diary (Chudleigh, 1950), did not include the account of the 1868 tsunami written in the original version. Future work would involve searching through entire, original diaries, and also examining entries for subsequent years following tsunami events.

Traditional forms of Māori knowledge including pūrākau (true stories), pakiwaitara (fairytale stories), mōteatea (laments), pepeha (quotations), whakatauki (proverbs) and waiata (songs) were not identified in this study. It is noted that 400 Māori relocated from the Chatham Islands to Taranaki following the tsunami event (Great Tidal Wave, 1914; Dennison, 1977; Holmes, 1984; Holmes, 1993; Lawrie & Powell, 2006; Simpson, 1950). Perhaps these forms of knowledge left the island with these people. Future work exploring Tangata Whenua knowledge of tsunami in the Chatham Islands could involve searching in Taranaki archives (people, marae, museums, and libraries).

3.6 Summary

This chapter meets Objective 2: to explore documented accounts and Tangata Whenua and/or local knowledge of past tsunami inundation and impacts on the Chatham Islands. The combination of documented accounts and Tangata Whenua knowledge provided a detailed summary of the impacts of the 1868, 1877, 1924, 1946 and 1960 tsunami, accompanied by inferred inundation extents for impacted locations. This study has brought new information to light and demonstrates how local and Tangata Whenua knowledge can be gathered and incorporated with documented accounts to gain a better understanding of tsunami hazard.

4 HAZARD SCENARIO DEVELOPMENT

4.1 INTRODUCTION

In order to assess exposure and vulnerability and form an infrastructure impact scenario of service loss for the participatory workshops (Chapter 6), a tsunami hazard footprint with an associated likelihood of occurrence, spatial extent and hazard parameter are required (Section 2.1.3.1).

The scenario developed in this chapter is designed to provide an example of potential tsunami inundation based on a 50 yr recurrence interval event for response and recovery planning in the Chatham Islands. A realistic case scenario, which provides a spatial inundation extent and depth parameter was compiled using the best scientific knowledge currently available. It is crucial to understand that this scenario is NOT A PREDICTION of future tsunami inundation.

This chapter firstly evaluates the suitability of available tsunami hazard models to be used for developing a tsunami scenario. Then the methods used to create a hybrid hazard scenario with a spatial extent and depth parameter are described. The resultant scenario is presented, which provides the basis for the impact assessment on infrastructure to evaluate service loss and to underpin the participatory community workshops described in the following Chapters. This chapter addresses Objective 3: to develop a suitable, credible tsunami inundation scenario. This chapter also explores the role of oral history and indigenous knowledge in hazard characterization for remote areas where hazard science is limited or uncertain due to lack of data.

4.2 SUITABILITY OF AVAILABLE HAZARD MODELS FOR USE AS A SCENARIO FOOTPRINT

Section 2.1.4.2.6 detailed the available tsunami hazard information and models for the Chatham Islands. This includes palaeo-tsunami investigations, probabilistic hazard curves and deaggregation plots, scenario-based hydrodynamic modelling for a regional and distant source tsunami, and rule-of-thumb (development level 2) evacuation zone modelling used to develop tsunami evacuation zones.

Palaeo-tsunami investigations on the Chatham Islands have only been conducted for a few locations; Okawa Point, Tupuangi/Cape Pattisson and Te Raki (Figure 16). While these investigations have contributed significantly to understanding historic and pre-historic tsunami occurrence on the Chatham

Islands, there are not enough study sites across the Islands to generate a comprehensive tsunami footprint.

Probabilistic hazard curves and deaggregation plots do not provide spatial information that can be incorporated into a tsunami hazard footprint. However, they provide information on the most likely source for a tsunami as well as the likelihood of various wave heights that may impact the Islands, thus are useful for determining the likelihood of a given scenario.

Peruvian Subduction Zone earthquakes are the most likely distant tsunami source for the Chatham Islands (Power, 2013b; Figure 19). Power (2013b) provides a wave height of >8 m for the Chatham Island coastline for a credible high-impact event generated from a distant source (Peru Subduction Zone). Tsunami wave heights of > 8 m occur around every 2,500 years (at the 84% confidence level).

Hikurangi Subduction Zone earthquakes are the most likely regional tsunami source (Power, 2013b; Figure 19). Mueller et al. (2016) provide a wave height of 8.0 m at Kaingaroa for a credible high-impact tsunami event generated from a regional source (the Hikurangi Subduction Zone). This wave height is expected to occur approximately every 2,500 years.

Power (2013b), include probabilistic hazard curves for the Chatham Islands coastline, providing approximate wave heights for various recurrence intervals (Table 11). However, due to the large uncertainties associated with probabilistic modelling (discussed in Section 1.3.5.2.2), these wave heights should be treated with considerable caution. Mueller et al. (2016) suggest the wave heights for long return period events provided in Table 11 may be overestimated and provided a revised wave height of > 8 m for a 2500 yr event at Kaingaroa (instead of 16 m provided by Power, 2013b). However, these probabilistic wave heights-at-coasts cannot provide impacts; inundation models are used to assess impacts.

Table 4.1. Approximate wave heights for 100, 500, 1000 and 2500 yr return periods for the main settlements on the Chatham Islands, provided by Power (2013a).Wave heights were taken from the 84% confidence interval from hazard curves.

Location	Return Period			
	100 yrs.	500 yrs.	1000 yrs.	2500 yrs.
Waitangi (Point Durham curve, p.514)	5 m	9 m	11 m	14.5 m
Kaingaroa (Matarakau curve, p.254)	6 m	10.5 m	13 m	16 m
Owenga and Flower Pott (Cape Fournier curve, p.528)	7 m	12.5 m	15 m	19 m
Port Hutt (Point Somes curve, p.518)	6 m	10 m	12.5 m	16 m

Scenario-based hydrodynamic models are commonly used for delineating tsunami hazard footprints to assess potential impacts (Williams 2016; Scheele, 2016; Le, 2016). Hydrodynamic models provide a spatial extent for tsunami inundation and include quantitative (if approximate) values for hazard parameters such as inundation depth and velocity. The hydrodynamic models for the Chatham Islands provide an inundation parameter (expressed by Lane et al., 2016, as maximum water elevation above mean sea level), maximum flow speed and a time series of tsunami wave arrivals. However, as mentioned in 1.3.3.2.4, there are many uncertainties associated with these models. Lane et al. (2016) stated “inundation results should be taken as the minimum inundation for the scenarios modelled because of the high uncertainties in the DEM” (p. 21). Thomas’s (2017) comparison of historical impacts from the 1868 event with the modelled inundation extent found that the models appear to underestimate the hazard and supports the contention that the modelled extents should be regarded as minima. Reducing the uncertainties of the hydrodynamic model through capturing higher-quality topographic data using Lidar was considered for this study. However, this was deemed too time-consuming for the small additional gain in accuracy, and more value was anticipated in the previously undocumented Tangata Whenua knowledge of historical tsunami events on the Chatham Islands (Chapter 3).

As mentioned in 1.3.3.2.5., rule of thumb (ROT) models involve applying an attenuation rule (wave run up height decreasing with distance inland) to an amplified (probabilistically or deterministically-derived) wave-height-at-coast allowing an inundation extent to be modelled (MCDEM, 2016a). Uncertainties are also associated with this type of modelling; the hazard is overestimated (although it remains suitable for the context of developing evacuation zones). As the inundation extent produced by the hydrodynamic modelling was uncertain and only to be used as a minimum, ROT modelling was used to inform evacuation zone development for the Chatham Islands.

New Zealand tsunami evacuation zones include a red, orange and yellow zone; each zone encompass areas susceptible to inundation (based on ROT modelling in the Chatham Islands), from a range of wave heights-at-coast. The zones guide authorities' decisions on what areas to evacuate based an expected tsunami size and are also designed to be used for self-evacuations during local source tsunami events when authorities do not have time to issue a warning and coordinate evacuations. For more information on how New Zealand and the Chatham Islands receive tsunami warnings see Appendix C. On the Chatham Islands:

- The red zone encompasses areas susceptible to inundation from tsunami less than 1 m wave-height-at-coast (Appendix C for more information).
- The orange zone encompasses areas susceptible to inundation from tsunami between 1 m - 8 m wave-height-at-coast and may inundate land (Appendix C for more information).
- The yellow zone encompasses the red and yellow zones and areas susceptible to tsunami inundation during large, (but infrequent – 500 yr + return period) >8 m tsunami (Appendix C for more information).

3 m, 5 m, 8 m and for 500 and 2500-year (which vary from 10-16 m at different sites) probabilistic wave-heights-at-coast provided by Power (2013a) were modelled for the Chatham Islands to inform the zones' delineation (H. Jack, ECan, personal communication, February 2017). The evacuation zones were considered as a potential tsunami inundation footprint for this study. However, while evacuation zones represent a wide range of scenarios, the whole zone is not expected to be inundated during a single event, thus would provide an overestimation of inundation. The zones are sometimes also projected out to land marks, such as roads to allow easy distinguishing between zones and may be extended to include important assets such as schools. Therefore, are not necessarily representative of the 'raw' ROT modelling result.

The investigation of past inundation extents and impacts recorded in documented accounts and Tangata Whenua knowledge in this study (Chapter 3) provided valuable insight into tsunami inundation in historical events. Of significant value is information on tsunami wave inundation in Waitangi around the Nairn river, which the models did not predict (Section 3.5.3). The investigation also provided an inundation extent for Taupeka and indications for inundation at Flower Pott, Pitt Island, which were not included in the modelling due to the main populated settlements taking priority (Lane et al., 2016). However, the footprint is incomplete and uncertain (Section 3.5.4) thus inadequate for use as the sole hazard footprint scenario.

4.3 Scenario Development Methods

As described above, available hazard models in their current state are not suitable by themselves to inform hazard scenarios to evaluate potential infrastructure impacts, derive expected levels of service, nor to provide the basis for the community workshop to evaluate impact reduction actions. In summary;

- The ROT models provide a complete scenario for the entire Chatham Island and Pitt Island coastline, but these models tend towards over-estimation of the hazard and would form an inundation scenario larger than could realistically be expected.
- The hydrodynamic inundation modelling provides a minimum inundation extent and depth parameter.
- The investigation of historical tsunami inundation extents provided valuable insights, but is incomplete with regards to inundation in areas other than those that key informant A and documented accounts cover.

With limited time and resources, re-modelling inundation was not possible. Therefore, it was decided that a suitable alternative would be to generate a hybrid hazard footprint incorporating information from available models. This hybrid hazard footprint was designed for preparedness initiatives (including drills). It is not intended or suitable for land-use planning or informing insurance policies. Design requirements of the hazard footprint scenario for the purposes of this study were to;

- Represent a credible tsunami event indicating possible inundation (not a prediction) that could occur from a range of sources (based on a probabilistic wave-height-at-coast).

- Include credible high-impact-generating inundation of key infrastructure assets to stimulate community discussion around potential consequences of service loss, and to identify actions to increase readiness and effectiveness of response and recovery initiatives.
- Exercise a specific evacuation zone (i.e. inundation within the orange zone) so that this scenario could be used during future preparedness exercises.

As described in Section 4.2, large uncertainties are associated with probabilistic wave-heights-at-coast and especially wave heights for longer return periods (such as the 2500 yr return period wave height which Mueller et al., 2016 revised). Probabilistic assessments of frequent events are also more useful and reliable for planning community resilience than probabilistic assessments of infrequent events that are unlikely to occur more than a few times in realistic planning timeframes (Davies, 2015). Power (2013b), indicated a 6 m wave height at the coast for Kaingaroa and Port Hutt (7 m at Owenga and Flower Pott and 5 m at Waitangi) for a 100 year return period. This wave height at the coast was observed at different locations during the 1868, 1924 and 1960 events (3 times in 150 years). Thus, a wave height at the coast of 6 m was applied to the whole coastline. Therefore the scenario is representative of an event that may occur every fifty or so years. For planning purposes a 6 m wave height at the coast would exercise the orange evacuation zone (Power, 2013a).

4.3.1 Inferring Scenario Inundation

All available spatial hazard models for the Chatham Islands, including the hydrodynamic inundation models for Hikurangi and Peru scenarios and ROT models for 3 m, 5 m, and >8 m wave heights at coast, and historical inundation extents derived in this study, were overlaid in GIS. The overlay allowed comparisons to be made between models to evaluate areas commonly inundated and other areas possibly susceptible to inundation from a 6 m wave-height-at-coast. Tangata Whenua knowledge of historical inundation and the changing environment was also used to evaluate reasons for differences between the models. Advice from ECan and UC hazard/risk specialists (expert judgement) was then sought to check the extents.

The overlay was examined in detail for Waitangi, Owenga and Kaingaroa as tsunami from all sources have been modelled in these areas. Port Hutt was included in the hydrodynamic and ROT modelling but lacks inundation information from the historical information. Pitt Island and the rest of the Chatham Island coastline were only included in the ROT modelling (due to priority given to larger populated coastal areas in the A-NZ-wide hydrodynamic modelling).

4.3.2 Inferring Depth Parameter

As discussed in Section 2.1.3.1, a hazard footprint requires a hazard parameter such as inundation depth or flow velocity to assess potential impacts through vulnerability models. The vulnerability function framework most suitable for this study is Williams' (2016) tsunami damage matrix, as justified in Section 2.1.3.3 and 5.3.3. Williams' (2016) tsunami damage matrix categorises impacts based on three inundation depth bins; 0 – 0.5 m, 0.5 – 2 m and >2 m. Therefore, inundation depth and these specific categories were used as the hazard intensity parameter for the scenario footprint.

Inundation depth data are yet to be accurately quantified for the Chatham Islands. The hydrodynamic scenarios provide an elevation above MSL instead of an inundation depth due to uncertainty about the accuracy of the Chatham Islands DEM (Lane et al., 2016) and inundation depth cannot be calculated from ROT models as they are based on an attenuation rule from run-up height not wave height (Leonard et al., 2008; Fraser & Power, 2013). Therefore, inundation depth for the scenario was inferred using expert judgment and Tangata Whenua knowledge. Site visits were made to evaluate potential inundation depths, which were justified by historical impacts.

4.4 Results

4.4.1 Scenario Inundation Extent

A scenario inundation extent was produced for Waitangi, Kaingaroa and Owenga; locations where inundation has been modelled (hydrodynamic and ROT) and historical information provided sufficient detail to map inundation extents (provided in Chapter 4). For the rest of the Island, the 5 m ROT model was used to indicate inundation extent; the 8 m ROT overestimates inundation for a 6 m scenario wave-height-at-coast, thus the 5 m ROT is more appropriate to use in this scenario.

4.4.1.1 Waitangi

Figure 33 allows comparison of modelled inundation in Waitangi and areas likely to be inundated in future events:

- Historic tsunami inundation during the 1868 and 1960 events occurred around the Nairn River. As discussed in Section 3.4.2.1.1, Tangata Whenua knowledge revealed that a substantial sand dune (which used to extend from the A-frame house to the mechanic shop) has since been both removed and eroded. The dune probably protected this area from being inundated during historical events, as the Peru and Hikurangi hydrodynamic models (Section 2.1.4.2.4) show tsunami energy refracting around Hanson Point and being re-directed towards the area west of the river; 3 m, 5 m and >8 m ROT models also inundate this area. It could be inferred that future tsunami could occur in this area due to the absence of the dune.

- Tangata Whenua knowledge of historical inundation and the ROT models both show inundation over the sand dune just west of Pages Corner.
- ROT models show inundation up the Nairn River and tributaries. Inundation also occurs west of the river and towards Lake Huro for the 5 m and 8 m inundation extents. This information aligns with Tangata Whenua knowledge that excess water in Waitangi drains south towards Maipito and east toward Lake Huro through the Mangape River. During the participatory workshops (Chapter 6) this was further supported; participants noted the Mangape River has silted up over time and is now less effective at draining excess water; as a result water tends to pool in the paddocks surrounding the creek (Section 6.3.1). Participants agreed that the scenario should be extended to the north-west (as shown in Figure 4.1).
- In both 1868 and 1960 events, the western corner of Waitangi Bay was inundated more, and were subjected to greater impacts, than the area towards the blowhole. This is also supported by the hydrodynamic scenarios and the ROT models.

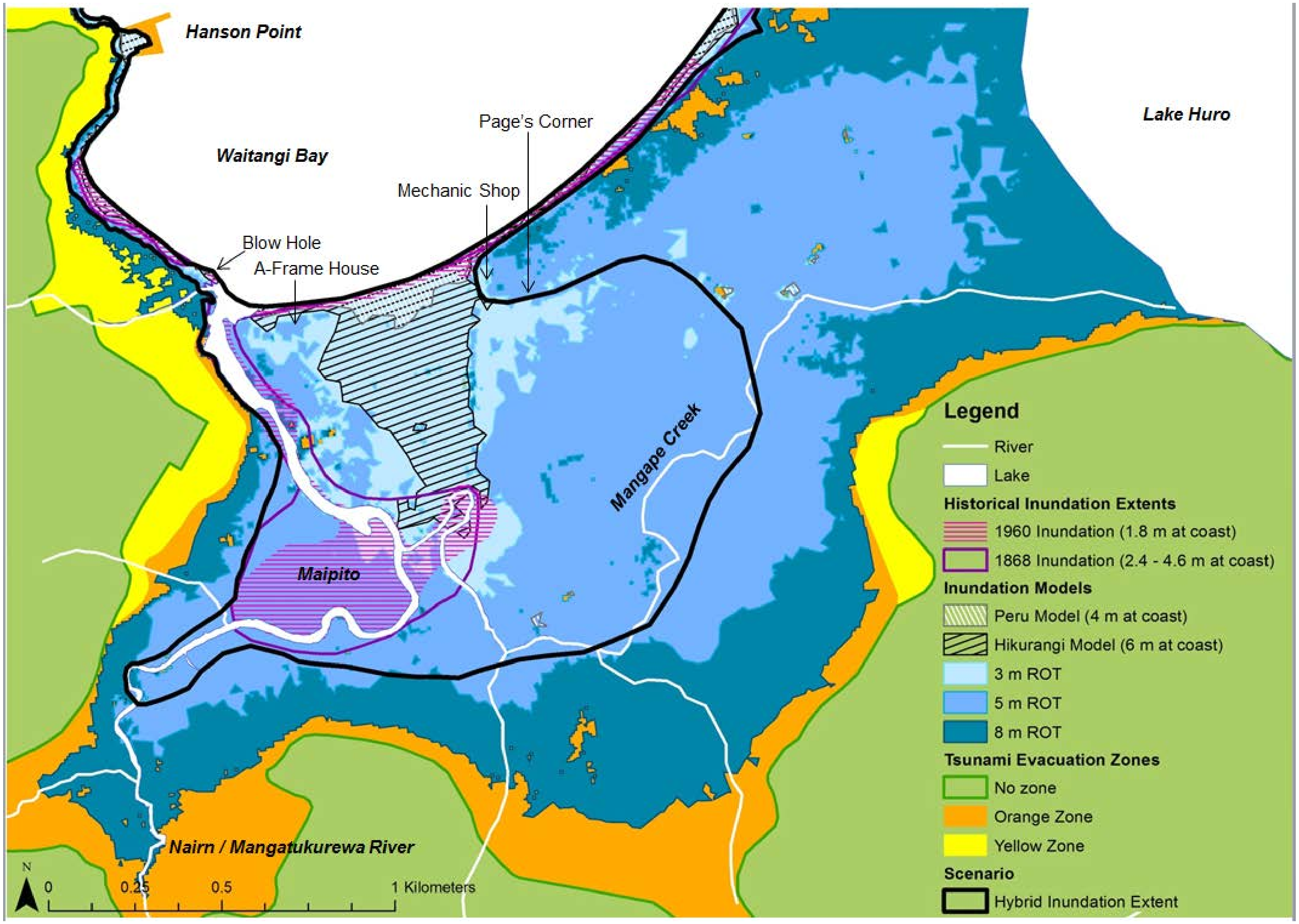

Figure 4.1. Overlay of available inundation models in Waitangi and the derived inundation extent. Models courtesy of Lane et al., 2016 and H. Jack, (personal communication).

The hazard footprint (black line in Figure 4.1) for Waitangi encompasses information from various models. The scenario encompasses all inundation extents (except the >8 m ROT) from the blowhole to the wharf, basically inundating to the bottom of the hill. The scenario extent then encompasses the historical inundation extents for 1868 and 1960 but extending to the south-west further up the Nairn River as indicated by the 5 m ROT model. The scenario extends south-south-east to incorporate tsunami energy refracted in this direction and extends west including the Mangape River towards Lake Huro. The eastern inundation extent is bounded by the sand dune (high elevation), but inundation breaches the part of the dune that was historically scoured and also modelled by the 3 m ROT model. Expert judgement estimated that 5 m ROT inundation in this area may be overestimating inundation based on the elevation and volume of the dunes.

4.4.1.2 Kaingaroa

All inundation models (3, 5 and 8 m ROT as well as Peru and Hukurangi hydrodynamic scenarios) indicate that energy is directed towards the middle of the Kaingaroa harbour and Lake Te Wapu, which is supported by historical impacts (Table 10). Historical tsunami inundation extents mostly align with the 5 m ROT model in Kaingaroa. Thus, the 5 m ROT model was used as the inundation scenario in and around Kaingaroa.

ROT models are conservative (provide an overestimation of the hazard, Section 2.1.4.2.5). Therefore, an assumption was made that an overestimation of inundation from a 5 m ROT model may be used to indicate potential inundation for a 6 m wave height (consistent with the scenario).

4.4.1.3 Owenga

Hazard models show extensive inundation inland north of Owenga near Mangahou and Kahiti Creeks; this area has low elevation and is marshy (NZ TOPO). The 1868 inundation extent in Owenga is very uncertain, based on a distorted inundation map (due to the understanding of the Island's shape at the time), and thus should be treated with caution. However, the more extensive inundation near Kahiti Creek is also indicated by the 1868 inundation (Figure 4.3, Section 4.4.1.3).

Hazard models also indicate inundation further up creeks and rivers in Owenga including Gillespie, Te One, Hawaiki and Cloughs Creeks. The scenario incorporates inundation extents of the 1924 event, Peru and Hikurangi hydrodynamic scenarios and mainly follows the 5 m ROT model as applied in Kaingaroa.

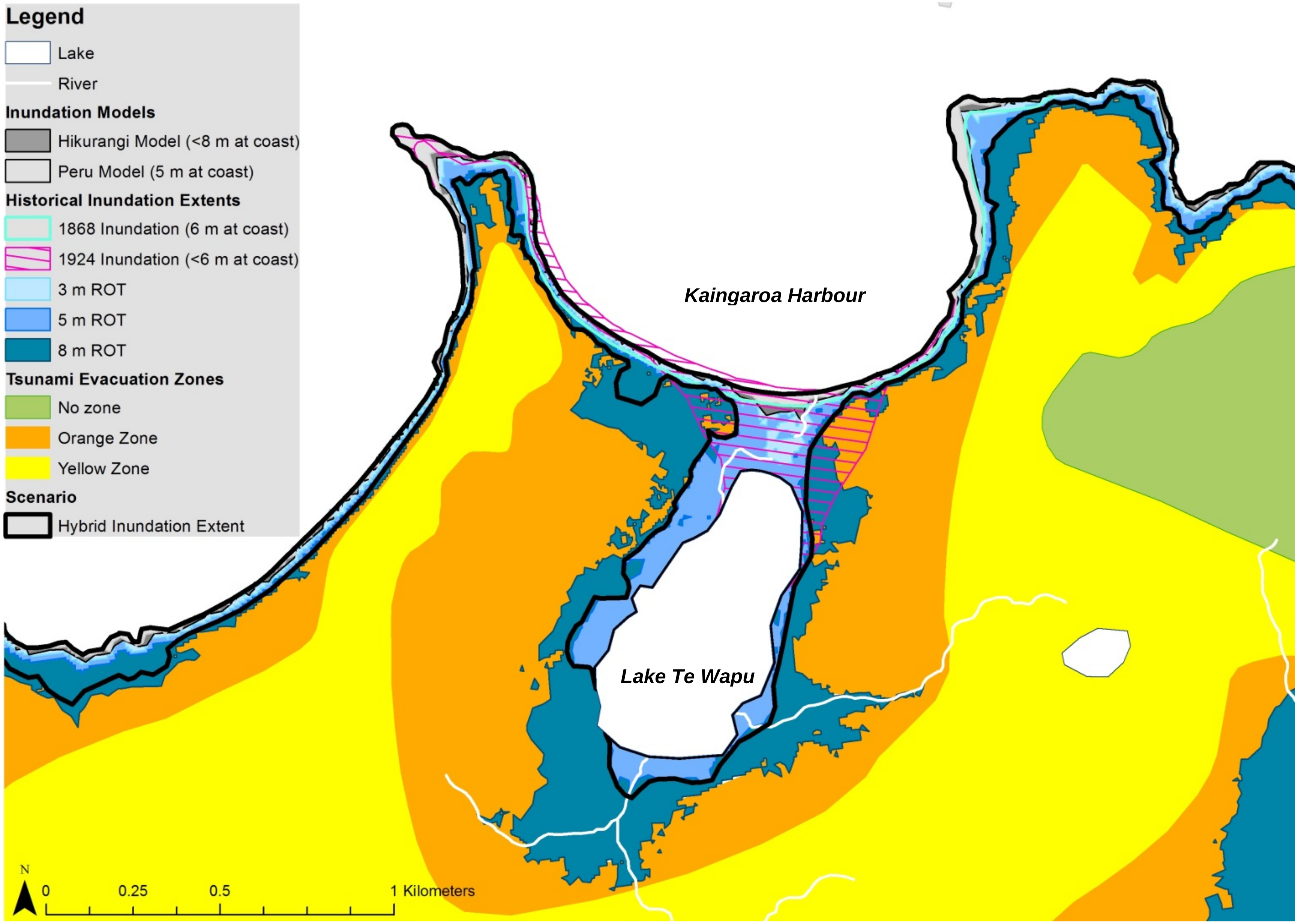

Figure 4.2. Overlay of available inundation models in Kaingaroa and the derived inundation extent. Models courtesy of Lane et al., 2016 and H. Jack, (personal communication).

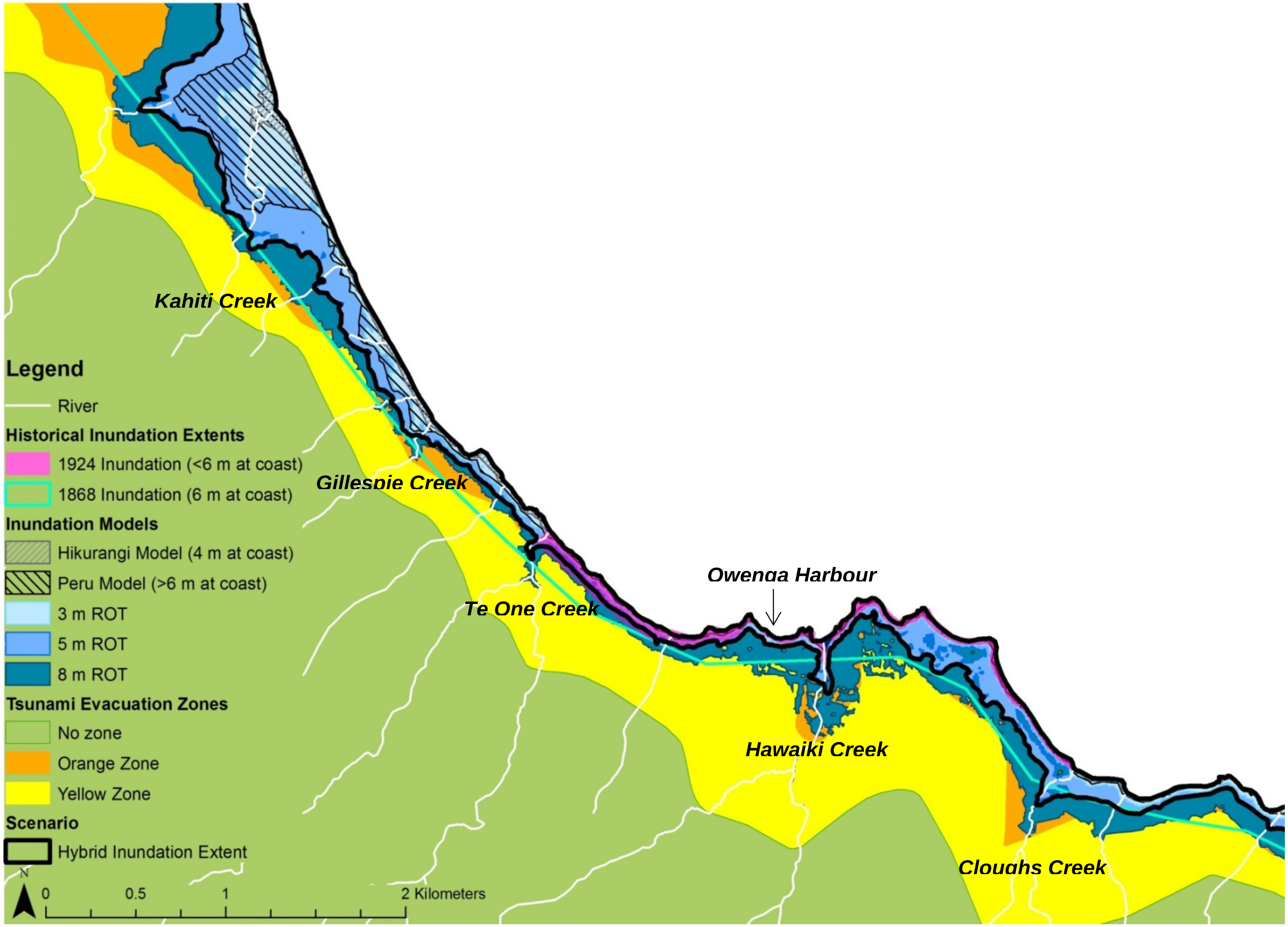

Figure 4.3. Overlay of available inundation models in Owenga and the derived inundation extent. Models courtesy of Lane et al., 2016 and H. Jack, (personal communication).

4.4.2 Inundation Depth Parameter

A depth parameter (0.0 m -0.5 m, 0.5 - 2 m and > 2 m) was assigned to the inundation extents developed.

4.4.2.1 Waitangi

Figure 4.4 shows the inferred depths for the scenario inundation in Waitangi. The deepest inundation, 2.0 m or greater, occurs near the Nairn River mouth and west of the river where tsunami energy is directed to areas of low elevation as discussed in 3.4.1.1. The 0.5-2.0 m depth parameter extends around the Nairn and its tributaries including areas that have been inundated in historical events (provided by Tangata Whenua knowledge), and providing a halo around the deepest inundation. The shallow inundation (<0.5 m) extends further inland onto slightly higher elevations.

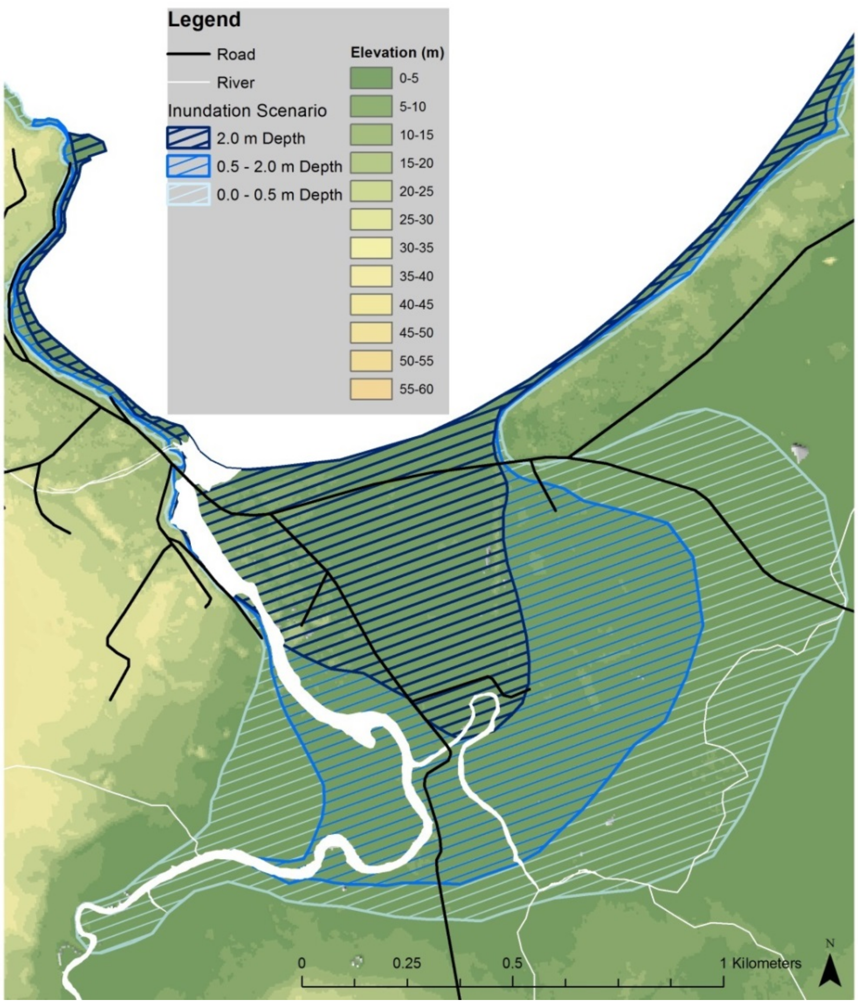

Figure 4.4. Tsunami inundation extent and depth scenario for Waitangi. Models courtesy of Lane et al., 2016 and H. Jack, (personal communication).

4.4.2.2 Owenga

Figure 4.5 shows the inferred depths for the scenario inundation in Owenga. Limited historical information was found to help derive the depth parameters, thus were formed using local knowledge of the topography. The deepest inundation, 2.0 m or greater, is restricted by the coastal bluff around Kaingaroa Harbour but extents across low elevation land and up creeks. The 0.5-2.0 m depth parameter 'overtops' the coastal bluff and extends further than the >2.0 m depth category. The shallow inundation (<0.5 m) extends further inland onto slightly higher elevations.

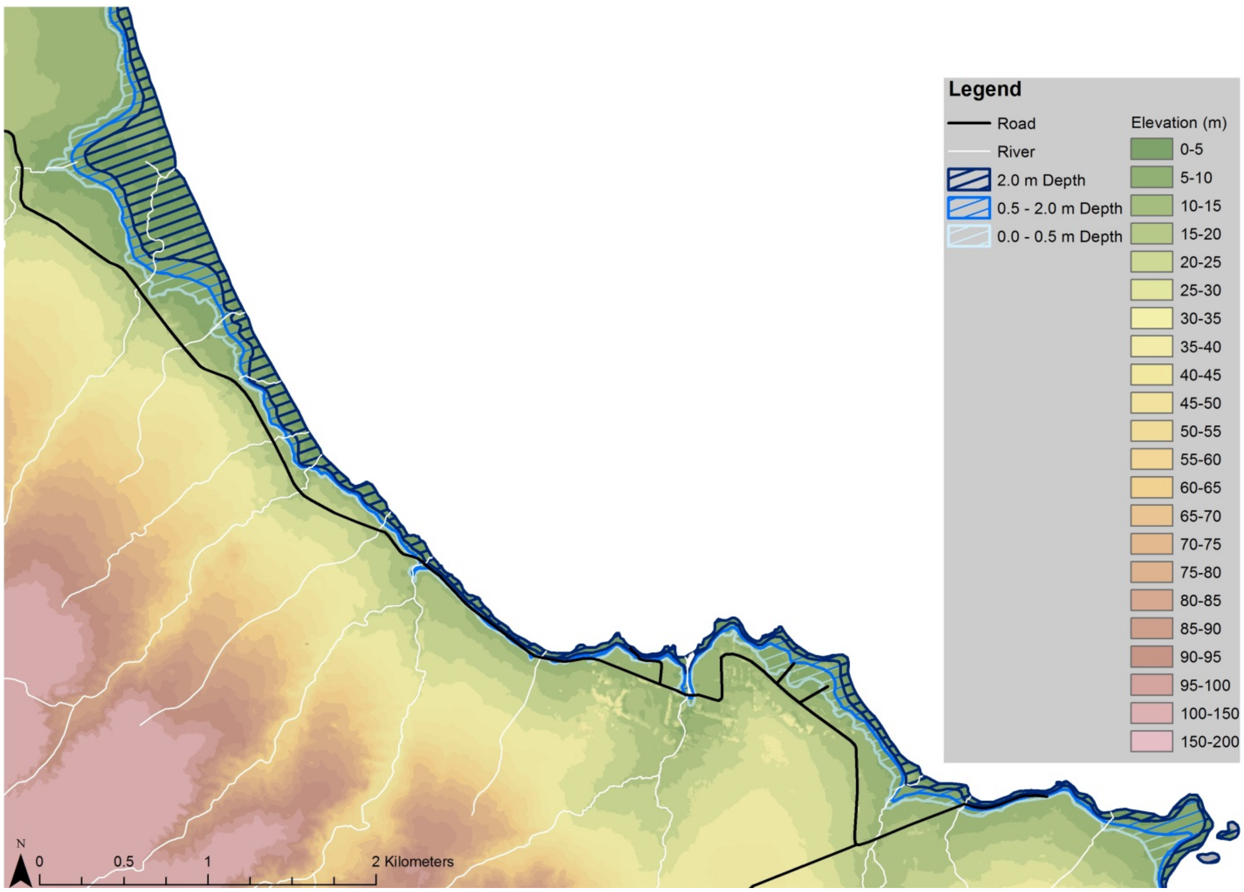

Figure 4.5. Tsunami inundation extent and depth scenario for Owenga.

4.4.2.3 Kaingaroa

Figure 4.6 shows the inferred depths for the scenario inundation in Kaingaroa. The deepest inundation, 2.0 m or greater, is restricted to around the 0-5 m contour and where local knowledge (of the author) identified localities of coastal banks and dunes (required due to the uncertain DEM). This depth extends inland near the lake and its river outlet, based on modelled extents and the impacts that occurred in

1924 (Table 2.1). The 0.5-2.0 m depth parameter extends further inland and up onto the 5-10 m elevation contour. The 0.0 m – 0.5 m inundation is then projected to the inundation extent.

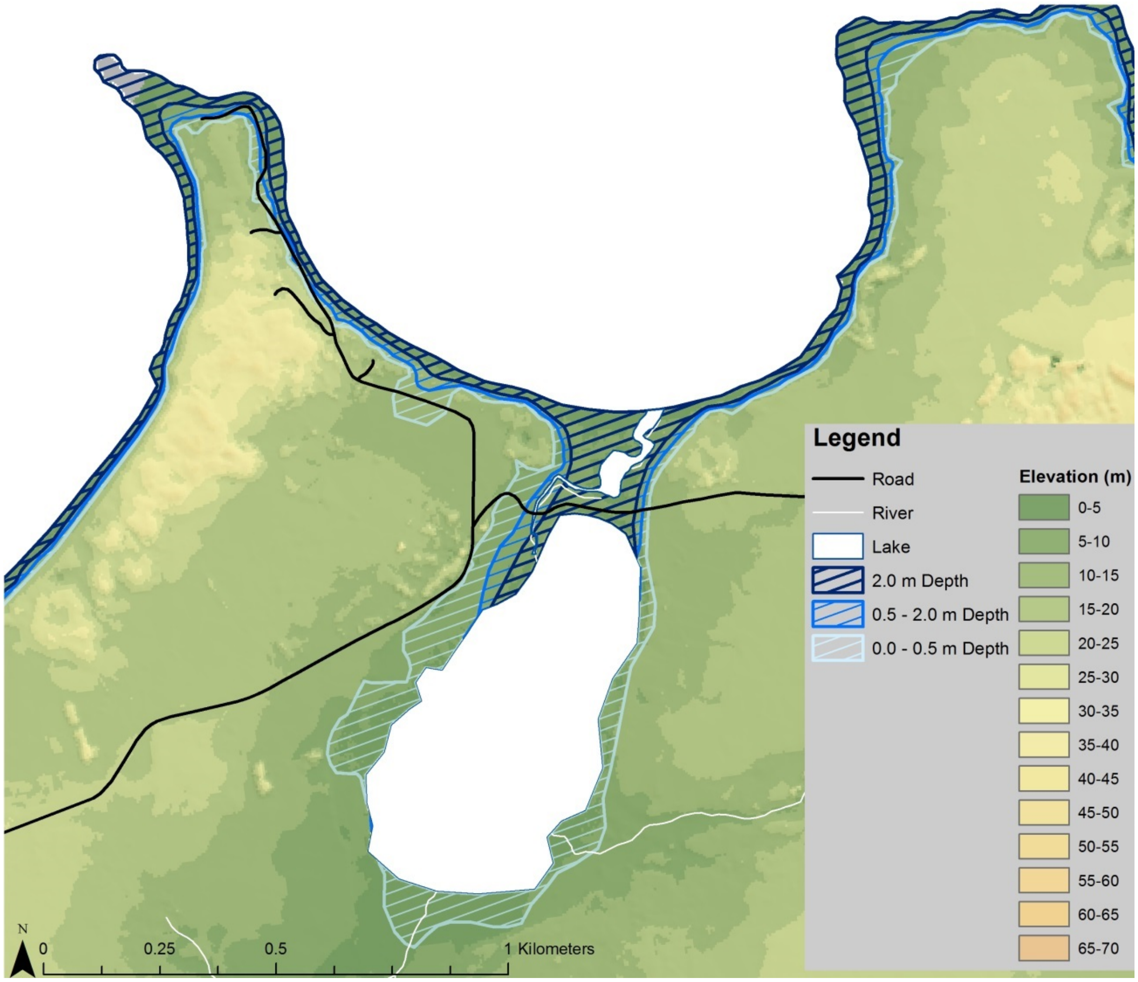

Figure 4.6. Tsunami inundation extent and depth scenario for Kaingaroa.

4.4.2.4 Other parts of the Island

For other areas around the island, some assumptions were made around the potential inundation depth:

- Any bridges within the 5 m ROT are assumed to be subjected to inundation depths of >2 m.
- Inundation of land on the west side of the lagoon will be subjected to inundation 0.0-0.5 m. This is based on the hydrodynamic modelling which produced low water elevation in the lagoon regardless of whether the lagoon was open or not (Lane et al., 2016).

4.5 DISCUSSION

Mercer et al. (2007, p. 247) advocated that scientists should access and incorporate indigenous knowledge data into hazard assessments rather than "just looking at new ways to explore old data or old methods". The methods included in this chapter provide a way to characterise hazards through scenario development in a remote area where routine scientific modelling is limited or uncertain due to lack of data. Tangata Whenua knowledge allowed development of a more credible scenario than if the methods only used the routine models (hydrodynamic and ROT).

4.5.1 Limitations and Future Work

There are several limitations involved in the methods to infer an inundation extent and depth parameter when available hazard models are also highly uncertain. These are listed below;

- The inundation extent was generated using information from probabilistic hazard analysis, Tangata Whenua knowledge and documented accounts of historical inundation extents, ROT models and hydrodynamic models. These all have their own associated uncertainties (1.3.3.2.3, 2.5.4, 1.3.3.2.5, 1.3.3.2.4). While there was not much that could be done to reduce the uncertainties associated with available models within the time constraints of this project; compiling and comparing all the models allowed some uncertainty to be reduced. Models that underestimated inundation were combined with models that overestimated hazard generating a more average scenario. A more average scenario is better suited for this study than an underestimated or overestimated extreme scenario. The purpose of the scenario is to provide the basis of the participatory community workshops (Chapter 6) to evaluate LoS and consequences to enhance preparedness (3.1). Extreme scenarios are unlikely to occur more than a few times in realistic planning timeframes (Davies, 2015), are less believable and may cause undue concern. Previous tsunami training exercises have been perceived by some staff as somewhat unrealistic and hard to take seriously (O. Pickles, personal communication, August 3, 2017). The average scenario is more believable and relatable to historical events which may lead to more investment in the scenario and the activities in the workshop (Section 6.4.1).
- A 6 m generic wave height was applied to all settlements when, in reality, wave heights will be (perhaps significantly) different along the coastline. However, this wave height occurs in each settlement approximately every 50 years or so.
- The inferred inundation depth incorporates the uncertainties of the DEM and Tangata Whenua knowledge as well as uncertainty in expert judgement including ontological (the unknown and

unexpected) uncertainty. Unexpected inundation could occur in future events not incorporated by this scenario. Unknown tsunami-generating sources, which have not been modelled, may generate inundation in unexpected areas (and may be inundate more than expected). Unexpected inundation may also occur due to uncertainties in the models; e.g. multiple successive waves are not considered in the inundation models, successive waves could scour sand dunes and inundate areas not anticipated by the models.

Developing the inundation and depth scenarios could have involved more participatory methods. The scenarios incorporated Tangata Whenua knowledge and were modified by members of the community during the participatory workshops (Chapter 6, Section 6.3.1). If there were more time for this study, a participatory mapping component could have been included to generate the scenario. Traditionally, participatory mapping exercises involve a group of people mapping their hazards, exposed assets and vulnerability in their communities (Cadag & Gaillard, 2012; Twigg, 2004; DRR Working Group, 2012; Benson et al., 2007). Future work could further explore community participation in scenario development for areas where high-quality data are not available. Based on key informant A and local knowledge of tsunami gathered in this study, a participatory scenario may allow incorporation of information relating to tsunami such as;

- Areas susceptible to inundation and ponding.
- Areas susceptible to scour and erosion.
- Water drainage directions and behaviour.
- Seasonal influence on river behaviour and flow rates which may influence tsunami inundation up rivers.
- Tidal influence on river behaviour and flow rates which may also influence tsunami inundation up rivers.
- Local tide and rip currents which may influence tsunami behaviour and inundation, and,
- Changes in the environment over time resulting in areas being more susceptible to inundation than they were during past events.

The scenario presented represents a credible, high-impact scenario, but does not consider seasons and how these may influence the extent of inundation (e.g. high river levels or existing ponding during winter may increase inundation extents); it is simply a 6 m wave height above mean high water spring tide level (MHWS). Future work could include consideration of seasons. Future scenarios could also be improved through generation of a LiDAR DEM to reduce uncertainty in the hydrodynamic modelling.

4.6 SUMMARY

While there is relatively high uncertainty associated with the inferred inundation extent and inundation depths, the scenario incorporates all available hazard information for the Chatham Islands and is fit for purpose for use in preparedness exercises.

The scenario:

- represents a credible, high-impact tsunami event indicating possible inundation (not a prediction) that could occur from a range of sources (based on a probabilistic wave-height-at-coast). But as stated earlier this scenario is not suitable to inform land-use planning or insurance.
- includes credible inundation of key infrastructure assets to stimulate community discussion around potential consequences of service loss, and to identify actions to reduce impacts, increase readiness and effectiveness of response and recovery initiatives.
- exercises the orange evacuation zone, (a Land and Marine Warning) so that this scenario could be used during future preparedness exercises.

This chapter addresses Objective 3: to develop a suitable, credible tsunami inundation scenario and highlights the role of oral history and indigenous knowledge in hazard characterization for remote areas where hazard science is limited or uncertain due to lack of data. The following chapter (Chapter 5) uses this scenario to assess tsunami impacts on infrastructure and to evaluate LoS in preparation for the participatory workshops (Chapter 6).

5 ASSESSING TSUNAMI IMPACTS ON LIFELINE INFRASTRUCTURE TO EVALUATE LOSS-OF-SERVICES

5.1 INTRODUCTION

The previous chapters of this thesis have focused on characterising tsunami hazard for the Chatham Islands as part of the risk identification stage within the risk assessment process (Section 1.3.5.2.1). However, risk identification also involves identifying exposed societal assets and considering their vulnerability in order to inform risk analysis to evaluate potential consequences (Section 1.3.5.2.1).

The objective of this chapter is to carry out an *ex ante* tsunami impact assessment on Chatham Islands infrastructure. Tsunami impacts on infrastructure can be evaluated by considering the vulnerability of the exposed assets to the hazard intensity, and producing estimates of the probable degree and spatial distribution of damage, and allowing potential LoS to be determined (Section 2.1.3.4.2). This chapter draws upon the literature review of tsunami impact assessment in Chapter 2 (Section 2.1.3) and the hazard model developed in Chapter 4 to identify exposed assets, consider vulnerability and evaluate levels of service. This will form an impact scenario for use in the participatory workshops (discussed in Chapter 6).

The methodology of this chapter involves firstly interviewing local infrastructure managers to gather an understanding of infrastructure systems on the Chatham Islands, their exposure, interdependencies, vulnerabilities and capacity to function following tsunami impact (addressing Objective 5). Field surveys and GIS were then used to: generate an up-to-date exposure inventory; identify hotspot and pinchpoint locations as well as network criticality; consider vulnerability; and model potential impacts and resultant LoS to form a credible tsunami impact scenario (Objectives 6 and 7). The exposure, vulnerability, impact and LoS modelling results are presented in various forms, including maps and tables, which are intended to constitute a comprehensive set of resources to inform the following chapter. The methodology and results are then critically discussed.

It is important to note that the impact summary notes provided in Section 5.4.3 are based on individual and collective understandings of the inundation scenario developed in Chapter 4. Levels of service were inferred for this inundation scenario only, and are not a prediction of the impacts that may occur during all future tsunami events.

5.2 Context For an Impact Assessment on Infrastructure

Tsunami that inundate coastal communities have the potential to inflict considerable damage on exposed infrastructure, affecting levels of service and causing significant disruption (Sections 2.1.2.2 & 2.1.3.3). In summary, infrastructure components can be damaged by:

- High flow velocities.
- Being inundated by multiple waves with inward and outward flows.
- Large forces in both directions: lateral hydrodynamic forces (some assets are designed to withstand seismic forces) and vertical buoyancy forces (infrastructure assets are not designed to withstand these).
- Debris strikes and damming (piling up and pushing against a structure).
- Sediment deposition.
- Salt water contamination and corrosion.
- and significant scouring (Horspool, Fraser & Mowll, 2015; Turnbull & Hughes, 2017).

The damage styles listed above can cause considerable impacts on exposed and vulnerable infrastructure components. Past tsunami including the Indian Ocean tsunami 2004, the Samoa tsunami 2009, the GEJ tsunami 2011, the Chile tsunami 2010 and the Illapel tsunami 2015 have highlighted that transport corridors, water networks, telecommunications, port facilities and electricity networks are vulnerable to tsunami impact (Horspool & Fraser, 2016). Impacts on these infrastructure networks and the resultant LoS have important implications for operation and distribution of response and recovery activities and can considerably affect how communities cope during a tsunami disaster (Deshmukh, Oh, & Hastak, 2011; Fotouhi et al., 2017; Blake et al., 2017 and others). A review of observed tsunami impacts on infrastructure components and key asset vulnerabilities is provided in Section 2.1.2.3.

During a high-impact tsunami event which affects locations across A-NZ, the Chatham Islands may be isolated from external assistance for an extended period of time, thus the performance of infrastructure components may be vital. Yet, there have been no previous contributions towards understanding how Chatham Island infrastructure may be impacted in a future tsunami event.

Evaluating potential tsunami impacts and resultant levels/loss of service is important for informing impact reduction planning to ensure infrastructure components remain safe, effective and operational during and after a tsunami event to provide essential services (UNISDR, 2015-2030). Evaluating potential impacts enables us to foresee what equipment/resources may be required to restore function and where response and recovery resources may need to be prioritised (Williams, 2016). The following Section describes the methods used to evaluate potential tsunami impacts on Chatham Islands, in order to develop a scenario to evaluate resultant levels of service and to inform future impact reduction initiatives.

5.3 Methods

The methods of this chapter follow an impact assessment framework. An overview of the methodology is shown in Figure 5.1, with the impact assessment process detailed in Figure 5.2. The methodology firstly involves gathering situational awareness of the infrastructure networks on the Chatham Islands and how they operate in order to update the exposure inventory, identify and map hotspots and pinchpoints and evaluate the criticality of the networks. Assessing exposure is part of the risk identification process within the Risk Management Framework (Section 1.3.5.2.1).

The hazard scenario developed in Chapter 4 (based on information from Chapter 3) is used as the hazard model for the impact assessment. The hazard scenario represents a credible, high-impact scenario based on 6 m wave-heights-at-coast which are associated with a return period of approximately 50 yrs. The footprint has a spatial inundation extent and depth parameter to estimate the vulnerability of exposed assets. The impact scenario is therefore deterministic as it is based on a single hazard scenario.

Vulnerability of infrastructure components was assessed using Williams' (2016) damage matrix by overlaying exposure information with the hazard model to determine probable damage to the asset; based on the inundation depth it was subjected to in the scenario. A method was then evaluated to use probable damage (from the matrix) to assign a damage state and infer a LoS. Service outage maps were then produced for use in the participatory workshops (Chapter 6).

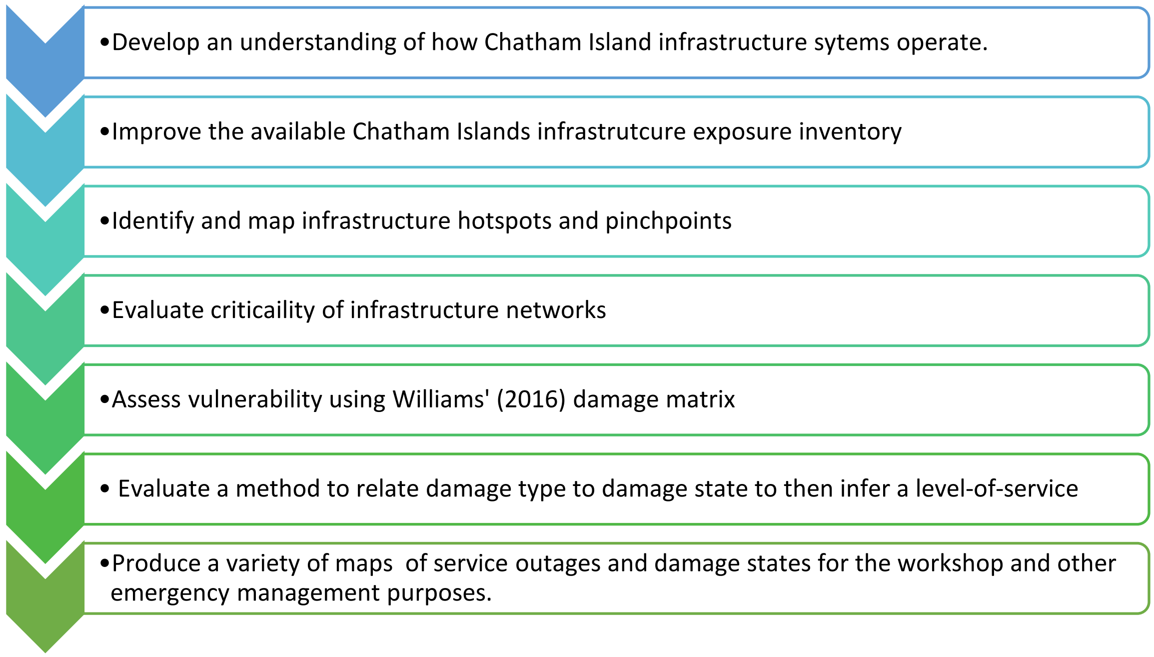

Figure 5.1. Overall methodology for Chapter 5.

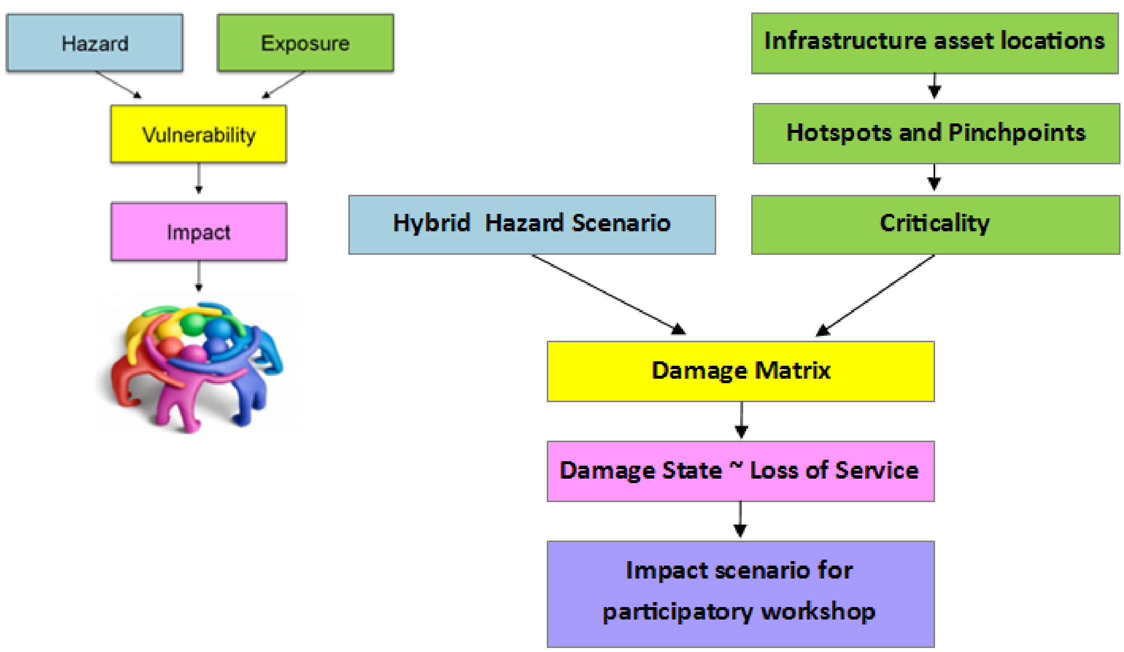

Figure 5.2. Impact assessment process (left), and the specific impact assessment process for tsunami damage to infrastructure (right).

The methodology followed for this *ex ante* tsunami impact assessment could be repeated for assessments of tsunami impacts to other assets (such as buildings); and to model impacts of other hazards. However it would be dependent on availability of relevant input parameters.

5.3.1 Understanding Exposure of Infrastructure Networks

Five semi-structured interviews were conducted with infrastructure managers to gain an understanding of exposure, vulnerability and potential impacts on the Chatham Islands infrastructure network. A literature review of tsunami impacts on infrastructure is provided in Section 2.1.2.3 which informed the infrastructure interview questions and the impact modelling process

A Human Ethics Committee Low Risk application for this work was approved by the University of Canterbury Ethics Committee. Company managers were approached to ask permission to interview employees and to indicate whether the company wished to be named in the research or not. Interviewees chose to remain anonymous or be named in the research.

Interview participants included chief executive officers and managers who possessed knowledge of communication, energy (including electricity and fuel), transport, and water infrastructure. Topics included:

- Situational awareness/exposure of infrastructure components and general operation of the network,
- Identifying components interviewees viewed as being vulnerable or susceptible to tsunami damage based on knowledge of components that may be 'weaker' based on:
    - experience with other hazards that cause inundation of components (flooding and storm surges),
    - environmental conditions the component is exposed to (e.g. exposure to high winds and salt water corrosion),
    - or age/wear and tear of components,
- Evaluating dependencies and interdependencies within and on other networks and discussing the consequences of components failing.
- Evaluating response and recovery needs by discussing:
    - Operative plans or initiatives.
    - Resources required to repair components and clean up.

- Available on-island resources to repair networks and resources that would be required from off-island (tipping points whereby the community will have to rely on external aid).

Mapping tools were used to locate assets and visualize networks (NZ Topo maps and Google Earth satellite imagery). Data were analysed by compiling information into themes associated with exposure, vulnerability and impact for each network, and were used to determine criteria for criticality ratings and inform scenario decisions.

5.3.2 Measuring Exposure

Thomas (2017) investigated available infrastructure data on the Chatham Islands. Limited digital data existed with most networks only mapped in paper form, except shapefiles developed by LINZ for Chatham Islands roads, buildings, some overhead electricity lines and airport polygons which are outdated or incomplete. Thus Thomas (2017) generated an exposure inventory of: up-to-date building locations, emergency service facilities, bridges, wharves, fuel stations, fuel tanks, communication towers, overhead electricity, buried electricity and power poles based on Google Earth 2015 satellite imagery. However, Thomas' (2017) inventory was incomplete and recommended improvement through further engagement with infrastructure providers, collecting GPS locations of assets and asset attributes for future studies.

5.3.2.1 Asset locations and attributes

Two field surveys were conducted on the Chatham Islands to collect GPS points and attribute data for infrastructure assets including bridges, wharves, road seal, culverts, transformers, fuel tanks, fuel pipelines, potable water components and sewerage components. A handheld Trimble GeoXH (GeoExplorer 2008 series) was used to collect GPS locations and data were downloaded to GIS for further analysis. Assets locations that could not be accessed during the field surveys (due to time restrictions accessing remote, off-road areas on private land) were provided by infrastructure managers during interviews and digitised on Google Earth Imagery. A comprehensive attribute collection was obtained, aligned to RiskScape modules for the exposure inventory. This was over and above what was required for the impact assessment as the vulnerability function used does not require attributes.

5.3.2.2 Asset Interactions and Criticality

As stated in Section 1.3.2.2, assessing exposure also requires an understanding of infrastructure interactions and component criticality. Understanding asset interactions and criticality allows the consequences or impacts of cascading failure to be predicted e.g. if a bridge with cables attached to it (a hotspot) is damaged, what areas will be without power? What does the line at this site service – critical facilities such as hospitals? Or a small street? Evaluating interactions and criticality allows a greater understanding of LoS and provides for identification of high priority areas for response and recovery.

5.3.2.3 Asset Interaction

Section 2.1.3.2.2. provides some methods of evaluating one-way dependencies and two-way infrastructure interdependencies. Pinpointing hotspots and pinchpoints (defined in Section 2.1.3.2.2.1) allows sites of potential cascading failures to be identified (Hughes and Healy, 2014; Sword-Daniels et al., 2015). Locating these sites can be achieved through GIS tools such as a kernel density analysis (Thacker et al., 2017). However, the Chatham Islands infrastructure network is a relatively small and simple case study, compared to city infrastructure. Therefore, expert judgement by infrastructure personnel (captured during semi-structured interviews) and field surveys were adequate methods to locate hotspots and pinchpoints. Field surveys identified sites where multiple infrastructure components (of the same and different networks) were co-located or intersected. Infrastructure personnel knowledge was then used to evaluate the interactions at that site, as well as the potential cascading effect of failure of the components at the site. These points were digitised in GIS.

5.3.2.4 Asset Criticality

As described in Section 2.1.3.2.2.2 criticality ratings consider the consequences of failure and areas for prioritisation for repair (Roberts, 2015). Most criticality ratings developed by lifeline groups involve applying a score to a network line based on its importance; measured by the kinds of facilities (e.g hospital, water treatment plant etc.) and the number of customers the line services (Bay of Plenty Lifelines Group & Aurecon, n.d; Auckland Engineering Lifelines, 2012; Roberts, 2015). The same method was applied for this study. A 4-point rating (1 = critical, 2 = important, 3 = moderate local influence, 4 = minor local influence) was applied to sections of the network to evaluate their importance (similarly defined by Bay of Plenty Lifelines Group & Aurecon, n.d).

Critical and important sections (ratings 1 and 2) were defined based on descriptions used by New Zealand lifeline companies (Bay of Plenty Lifelines Group & Aurecon, n.d; Auckland Engineering Lifelines, 2012; Roberts, 2015; Table 5.1). The number of houses to differentiate between moderate and minor influence was based on expert opinion of recovery tipping points from infrastructure managers. Infrastructure managers stated that if there were not enough resources to repair a network (e.g. spare power poles), areas of minor influence (such as a small street) may be disconnected in order to service critical, important and moderate local areas (I. Sanson, personal communication, August 2017). Small streets on the Chatham Islands typically contain less than 10 households. Therefore, network lines that service these areas are defined as minor local influence. Network lines that have moderate local influence service a greater number of households, typically between 10-30 households. Major local influence was not a category included in this study, as by comparison, A-NZ criticality ratings include thousands of customers for major/regional/national influence (Auckland Engineering Lifelines, 2012).

Table 5.1. Hotspot, Pinchpoints and Asset Criticality Rating (adapted from Auckland Engineering Lifelines, 2012; Aurecon and Bay of Plenty Lifelines Group, 2014; Roberts, n.d; Roberts, 2015).

Criticality Rating	Description
1. Critical	Essential for the operation and distribution of emergency services for preservation of life.
2. Important	Important for economic continuity as well as social and cultural welfare.
3. Moderate local influence	Loss of service poses no risk to life, effects are localized to between 10 and 30 households
4. Minor local influence	Loss of service poses no risk to life, effects are localised to less than 10 households

Google Earth Imagery was used to count the number of households each network line serviced. A 'trumping' system was also used to consider networks that may have a local influence but also service a critical or important facility. Critical lines 'trump' all other categories, and important lines 'trump' local influences. For example, if a line services less than ten households it would be considered a minor local influence line, but if the line also services a hospital it would be categorised as a critical line instead.

A single line was used to represent criticality of road, electricity and landline networks as they are mostly co-located, or only a few meters apart. Criticality also considered network function such as directional flow (based on information provided in Section 4.4.1.1); for example, the whole line from the electricity generation plant to the hospital is deemed critical because if an asset is damaged at any point along this line, the whole network is affected. This line also allows the criticality of hotspots and pinchpoints to be evaluated. Hotspots and pinchpoint criticality can be evaluated based on the line it is located on.

5.3.2.5 Exposure to the Hazard Model

To assess exposure of infrastructure components to the hazard scenario, the infrastructure inventory network was overlaid on the hazard scenario in GIS. The identity spatial analysis tool was used to combine attributes of both shapefiles to evaluate the number or length of infrastructure components that are exposed to each measure of hazard intensity for the purpose of later assigning an associated measure of vulnerability.

5.3.3 Vulnerability

Based on the literature review in Section 2.1.3.3, Williams' (2016) damage matrix (updated by Horspool & Fraser, 2016) is the most suitable vulnerability function for application to Chatham Islands infrastructure and to apply to the hazard metric used in this study. As stated in Section 2.1.3.3, the metric provided a probable (low, medium or high probability) damage type for assets exposed to three inundation depth categories (0.0-0.5 m, 0.5-2 m, >2 m). While Williams (2016) states that the damage matrix is relatively low-resolution, it provides a vulnerability metric to use for all infrastructure types included in this study in the absence of locally applicable fragility curves. The matrix is also suitable to the hazard metric; detailed, credible depth parameters that fragility curves require to assess damage are not available due to absence of a LiDAR- quality DEM.

5.3.4 Impact

Damage states (DS) represent a degree of damage and are used to illustrate impact (Section 2.1.3.4.1). Levels of service (LoS) can also be applied to express impact and are used to generate outage maps which provide useful information for readiness, response and recovery initiatives.

Some vulnerability metrics provide a damage state as an output (e.g. Horspool & Fraser, 2016). However, Williams' (2016) damage matrix only provides a description of damage. Therefore, a method was required to evaluate DS and LoS from the damage description. Horspool & Fraser (2016) relate DS and LoS (which they define as serviceability) through a description; used in fragility function development (Table 5.2).

Table 5.2.Retrieved from Horspool & Fraser (2016, p.80)

Damage State	Description	Serviceability
Damage State 1 (Rank C)	Minor damage, often from impacts, to the superstructure.	Operating as normal, needs minor repairs
Damage State 2 (Rank B)	Major damage to superstructure but still in place on piers. Superstructure may have been shifted.	Operating under speed and load restrictions or not operating if superstructure has shifted. Requires moderate-major repairs. If superstructure has moved bridge may need to be demolished.
Damage State 3 (Rank A)	Complete washout of superstructure	Not operating. Bridge will need to be rebuilt on new piles.

This method was applied to evaluate DS from the matrix description to then infer LoS. A table relating the damage matrix description to DS and LoS was constructed for exposed infrastructure components on the Chatham Islands. Horspool and Fraser (2016) provide relationships between DS, description and LoS for roads, bridges, substations and utility poles. For these infrastructure components and others, the relationship was defined by expert opinion (local infrastructure managers) and literature review.

Firstly, DS and LoS criteria needed to be established to apply to this study. LoS can be expressed as a percentage of full service e.g. serviceability 0.4 (e.g. Robinson et al., 2014; Buxton et al 2014); or as a description assigned with a value (e.g. DS 1) which commonly include the descriptions: full service, partial service and no service (e.g. Horspool & Fraser, 2016; Blake et al 2017; Deligne et al., 2017). Damage states are usually expressed qualitatively as a degree of damage (e.g. minor, moderate, major, and complete) and some include a description of the expected functionality in that damage state (e.g. operational after extensive structural repairs) (Robinson et al., 2015; Horspool & Fraser 2015; Horspool & Fraser 2016; Williams, 2016; Williams, 2016a).

Different DS and LoS criteria are sometimes established specifically for different infrastructure types; more so in studies that focus on a few particular assets such as roads or electricity (Horspool & Fraser, 2016; Blake et al 2017; Deligne et al., 2017). For this study, one set of damage state criteria was established and applied to all infrastructure networks, similarly to Robinson et al., 2014 and Buxton et al., 2014. The DS and LoS criteria applied in this study are presented in Tables 5.3 and 5.4. Damage states were assigned based on the description of damage provided by the matrix, Horspool & Fraser's (2016) LoS-DS tables (for roads, bridges, substations and utility poles) and literature review. Levels of service were then assigned based on the description and damage state, informed by expert opinion (infrastructure managers) and literature review.

Table 5.3. Damage state criteria chosen for this study. Based on Horspool & Fraser (2016), and Williams, (2016)

Damage State	Description
DS0	No damage, no clean up or repairs required
DS1	Minor damage, minor repairs and/or clean up
DS2	Moderate damage, major repairs and replacement of some parts
DS3	destroyed asset, demolish and rebuild required

Table 5.4. Damage state criteria. Based on Blake et al., 2017 and Deligne et al., 2017

Level-of-Service	Description
LS1	Full Service: Component is functional
LS2	Partial Service: Rolling outages, or restricted use
LS3	No Service: Component has failed, no functionality

5.4 Results

5.4.1 Exposure Assessment

This begins with establishing some context of the infrastructure system on the Chatham Islands (Section 5.4.1.1). This information then informed an analysis of evaluating hotspots, pinchpoints and criticality (Section 5.4.1.2) which provided a more detailed analysis of the assets exposed to the inundation scenario, presented in Section 5.4.1.3.

5.4.1.1 Chatham Island Infrastructure: Network Characterisation

Information from interviews with infrastructure managers was compiled into the following systematic overview of communications, transportation, energy and water infrastructure; system design, key vulnerabilities, interdependencies and capacities within the network, and tsunami operational procedures.

5.4.1.1.1 Communications

Modes of communication on the Chatham Islands include word-of-mouth, fax, landline, internet messaging, VHF radio, and satellite phones during emergencies; there is no cellular reception. The communication network between A-NZ and the Chatham Islands operates via satellite connection. There is only capability to operate 15 external calls/lines through the satellite at one time (R. Phillips, personal communication, 2 August, 2017). Internal communications operate via exchange units, radio towers (for VHF), copper cable (landline) and repeaters (for phone and internet).

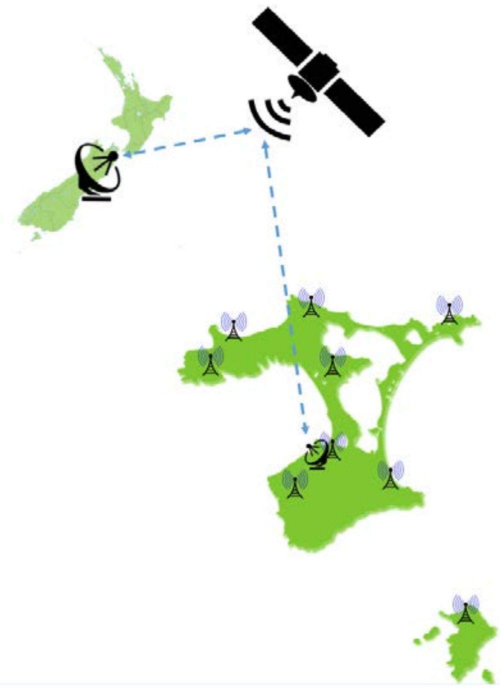

Figure 5.3. Conceptual diagram of external and internal communication on the Chatham Islands, illustrating satellite connection through exchange centres and the signal being repeated at repeater sites across the islands.

Telecommunications are a vital asset during tsunami warning, response and recovery on the Chatham Islands. During a tsunami warning, the Mayor, Council Chief Executive and Emergency Management Officer are contacted by the Ministry of Civil Defence and Emergency Management (MCDEM, in Wellington), via automated phone call and email. If evacuation is warranted, area coordinators[6] are called who then

[6] Area coordinators are designated members of the community responsible for contacting everyone in their area and coordinating evacuation of community members located in evacuation zones to a welfare centre or a safe site (if they are off-island a deputy is assigned) (Chatham Islands Civil Defence Emergency Management Group Plan 2013-2016). Area coordinators then assist welfare personnel or assume the role of Welfare Manager and settle community members into a welfare centre. Area coordinators maintain registration of evacuees, their whereabouts and a record of any missing persons while maintaining contact with the EOC (Chatham Islands Civil Defence Emergency Management Group Plan 2013-2016). In addition, the area coordinator can manage a self-evacuation locally if required. This is particularly important for the more isolated settlements such as Kaingaroa.

contact residents in their area via land-line or radio, and remain in contact with the Emergency Operations Center (EOC) (O. Pickles, personal communication, August 3, 2017).

Communications are required to receive updates from MCDEM during a warning and to disseminate these messages through the process outlined above. External communications will also be necessary in recovery to coordinate external resources that may be required for response and recovery (O. Pickles, personal communication, August 3, 2017).

5.4.1.1.1.1 Exposure Vulnerability and Interdependencies

The most exposed communication asset to direct tsunami impact is the landline network; particularly in low lying Waitangi, and the cable that is attached to the Waitangi Bridge. Most other communication assets (repeaters, exchanges and towers) are located on high ground, or inland (R. Phillips, personal communication, 2 August, 2017).

The communications system is vulnerable due to its dependency on satellite connection and electricity (including the fuel supply to generate electricity), as follows:

- the central exchange is powered by its own generator, but is dependent on fuel supply,
- some repeaters rely on the main electricity grid (most repeaters are powered by solar energy),
- external communications is dependent on the operation of the exchange and satellite connection. The satellite link is critical for receiving tsunami warning; if you lose satellite connection you lose external communications to A-NZ (but could still communicate locally). During the opening of Kopinga Marae (2005), the satellite connection failed, there was no eftpos and the airport could not operate due to inability to lodge flight plans (R. Phillips, personal communication, 2 August, 2017).

5.4.1.1.1.2 Capacity and Operational Plans

There are several capacities within the communication network if the landline and/or electricity network is damaged and services are reduced. The VHF radio system is resilient and is used when other communications fail. A lot of people on the island have fisherman's radios in their homes and in their vehicles. Satellite phones and VHF radios (which some fishermen have) can be used to communicate externally (assuming they are charged before the event). Repeaters that are reliant on mains electricity do have a limited battery life (6 hours), and there is back-up fuel for the central exchange (there is a 4000 L tank at the exchange which holds approximately 2-3 weeks supply if it is full) (R. Phillips, personal communication, 2 August, 2017).

There is an Emergency Communication Plan for the Chatham Islands (CIC, 2007, in review), which outlines: the communication processes involved in pre/post warning confirmation, a key contact list for personnel (EOC staff, CDEM Group, area coordinators), communication equipment, radio channels, and an on-island inventory of equipment and resources. There are no plans for restoring communications on the Chatham Islands following a tsunami event (R. Phillips, personal communication, 2 August, 2017). Depending on the extent of the damage, additional staff may be needed (only one staff member resides on the Chatham Islands) as well as resources (tools and parts) to repair or replace components. There are some ‘bits and pieces’ to work with on-island, and ways of making things work, but the Chatham Island communication network is pretty limited in terms of resources if there is extensive damage (R. Phillips, personal communication, 2 August, 2017). Cabling is heavy and would require transportation via ship which in normal time can take a month to order and receive. Other light resources (such as electronic cards for exchanges) could be flown to the Islands.

5.4.1.1.2 Transportation

The social and economic well-being of the Chatham Islands depends on transportation infrastructure including sea and air ports, roads and bridges, diesel supply (for electricity generation, fishing vessels and vehicles), food and other supplies. Transportation infrastructure is also vital for the provision of emergency services and repair of other lifeline infrastructure components. Transportation infrastructure such as wharves, bridges and roads are important during post-tsunami response and timely recovery for distribution of aid and resources.

5.4.1.1.2.1 Airport

There is a small airport on the Chatham Island, the Inia William Tuuta Memorial Airport as well as two grass airstrips, one on Pitt Island and one at Hapupu on Chatham Island (Figure 4.4). The fleet of Air Chathams aircrafts that usually service the Chathams includes two Convair 580’s and a Cessna 206 (Figure 4.4). The Cessna services Pitt Island, flying on demand carrying everything from passengers, mail, animals, live lobster and freight (Air Chathams, n.d). The Convairs (one with passenger/freight capability and one with a 50 seat passenger configuration with large cargo holds) fly cargo (including passengers, seafood exports, groceries and other freight) to and from the Chatham Islands via a two-hour plane journey, five times a week. The usual schedule includes three flights a week to Wellington, once a week (or twice in busy periods) to Auckland and once to Christchurch (Air Chathams, n.d).

Figure 5.4. Left: Inia William Tuuta Memorial Airport on Chatham Island. Top left: the two Convair aircrafts at the airport. Bottom left: Cessna at Pitt Island airstrip. Photographs retrieved from Air Chathams (n.d).

5.4.1.1.2.2 Exposure Vulnerability and Interdependencies

The Inia William Tuuta Memorial Airport has a bitumen runway, passenger terminal (orange roof in Figure 4.4), freight storage shed (dark grey roof), hangar bay for the Cessna (light grey), back-up electricity generator, avgas fuel tanks, fuel tanker vehicle, rainwater tanks and forklifts. The airport is located on relatively low lying land (13 m above MSL, GPS) beside Te Whanga Lagoon (B. Harris, personal communication, August 2, 2016). The airport was built on wet peat marshland, which was infilled and levelled (Key respondent A), thus could be vulnerable to scour and tsunami-induced liquefaction (Yeh, Sato & Tajima, 2013; Williams, 2016).

The air transportation network is dependent on other infrastructure including:

- Supply (and shelf life) of AvGas Fuel.
- Electricity (back-up generator located at the airport if the main grid is disrupted).
- Communication infrastructure components for navigation and lodging flight plans.
- Flying to Pitt requires operational grass or bitumen landing strip on Chatham Island (B. Harris, personal communication, August 2, 2016).

5.4.1.1.2.3 Capacity and Operational Plans

There is some capacity in the air transportation network. Convair aircraft are generally capable of landing in conditions which other aircraft cannot. So if there was some tarmac damage, it may still be possible to use the runway (depending on the damage). Local authorities would prefer Convairs to be landing on bitumen but do have a grass strip capability. However, grass strips are dangerous when wet so if these were inundated with water, they would be unusable. Local authorities would use their capacities as best they could to restore function of the airport, but in a major event extensive damage would require assistance from the New Zealand Government (DIA, MCDEM) (B. Harris, personal communication, August 2, 2016).

The Chatham Islands Airport has an emergency response plan (a requirement of holding an Aerodrome Operating Certificate under civil aviation rules, part 139) (Civil Aviation Act, 1990). However, there is no specific plan for tsunami response.

5.4.1.1.2.4 Wharves

Wharves on the Chatham Islands are key community assets in terms of livelihoods, economic growth and essential supplies (Guy, 2011). There are four main wharves: Waitangi Wharf, Owenga Wharf, Kaingaroa Wharf and Pitt Island Wharf (Flower Pott). There are also two small private jetties at Port Hutt. As described in Section 2.1.2.3.1.3, wharf assets including fishing vessels and equipment are susceptible to tsunami impact. Table 5.5 provides a summary of exposed assets at each wharf, detailed descriptions of each wharf are then provided.

Table 5.5. Chatham Island Wharves and their exposed assets. Green indicates the wharves have these assets, grey indicates the wharf does not. Holding pots sit outside the wharves and are used by fisherman to store crayfish, that sometimes wash up in storms. This table was generated based on information provided by Chatham Islands Harbour Master and Ports Officer (personal communication, August 7, 2017).

Wharves	Assets				
	Approx. No. of Vessels	No. of Swing Moorings	No. non-operational vessels	Holding Pots	Fuel line
Waitangi	13	17	1		
Owenga	11	11	0		
Kaingaroa	6	6	0		
Port Hutt	2	0	2		
Flower Pott	6	0	0		

Waitangi Wharf

Waitangi Wharf is the main trading port and is the only port with capacity to berth cargo ships and manage essential cargo such as fuel, machinery, vehicles, food and other supplies for the isolated Chatham Islands community (Memorial Park Alliance, 2015). Waitangi Wharf is an open sea environment and has recently been reconstructed, a $56 million-dollar project. The wharf opened in March 2018 but is still being completed (April 2018) (Tonkin + Taylor, 2018). The construction of the new port included a 180m breakwater (made from 3,000 xbloc concrete armor units), the reclamation of 9,500m^2 of land, the dredging of the approach and berthing area, improved cargo, stock and biosecurity facilities and replacement of the Fisherman's Wharf to allow access for multiple recreational and commercial fishing vessels at one time (Memorial Park Alliance, 2015). The original wharf design plans have changed multiple times over the course of construction. Due to this, and to access restrictions during field surveys (due to construction) a complete survey of fuel, electricity, communications, and water infrastructure attached to the wharf was not carried out for this study.

Waitangi wharf is used by a large fleet of fishing vessels (approximately 13) which use the fisherman's wharf (small wharf to the Bottom Right in Figure 4.5). The cargo ship (currently the Southern Tiare) brings freight from Timaru and Napier once a month on average, but sometimes makes weekly trips during busy periods. There are also three long line fishing boats which land deep sea fish at Waitangi Port and anchor (or tie to the wharf) once or twice a month (Chatham Island Harbour Master and Ports Officer, personal communication, August 7, 2017).

Figure 5.5. Waitangi Port (still in construction, as of April 2018). Top image courtesy of authors family. Bottom image retrieved from Tonkin + Taylor (2018).

5.4.1.1.2.5 Exposure Vulnerability and Interdependencies

Waitangi Wharf, and the other wharves around the island, may be impacted during a future tsunami. Several wharf components are vulnerable to tsunami impact:

- The new breakwater structure at Waitangi is designed to be overtopped but some are skeptical as to whether the components will remain intact during overtopping by frequent strong southwest swells (predominant wind, swell and storm direction), let alone tsunami inundation. Xbloc components would be in the area of direct impact from a tsunami. They may become dislodged by a tsunami and be carried into the bay impacting other structures (Chatham Island Harbour Master and Ports Officer, personal communication, August 7, 2017).
- Containers at Waitangi, Owenga, and Flower Pott may move as they are not locked to the ground. They are only locked to each other when stacked.
- Depending on the new Waitangi wharf design, there may be fuel sitting in the pipeline that may be impacted. In the old pipeline for the old wharf, there was approximately 3000L sitting in the pipe (Chatham Island Harbour Master and Ports Officer, personal communication, August 7, 2017). Fuel tanks and the pump shed may also be vulnerable as they are close to the shore. All bulk fuel tanks have bunding around them to prevent spills, or they are self-bunded (tank within a tank). However, if the bunding is overtopped other components like bowsers and pipeline may be damaged and fuel may spill. One of the bulk fuel tanks is designed to be a fuel barge towed behind a boat so depending on how much fuel is in the tank at the time, it might float.
- If it is a high-impact event, damage could occur to the berthing structure at Waitangi wharf, preventing vessels from berthing safely.
- Sediment changes could also be an issue. The dredged area at Waitangi and Flower Pott may be filled and require future dredging. Rocks around all harbours may move and become maritime hazards. There is no resident dredge thus delays in accessing an available dredge may slow recovery (Chatham Island Harbour Master and Ports Officer, personal communication, August 7, 2017).

Fuel on the wharf for fishing vessels is dependent on fuel infrastructure (pipeline and pumps) and electricity (to operate pumps). Wharves are still usable if electricity and fuel lines are non-operational but crew would need to cart fuel to their vessels (Chatham Island Harbour Master and Ports Officer, personal communication, August 7, 2017). As noted above there is a key dependence by the community on the operation of the port for the economy and people’s livelihoods.

5.4.1.1.2.6 Capacity and Operational Plans

No plan exists specifically for wharf remediation on the Chatham Islands following tsunami impact. Wharves are also owned and operated by different companies thus response and recovery decisions may be subject to the owners' independent decisions. Nevertheless, local authorities would focus on remediation of Waitangi Port, and on other ports using available resources as quickly as possible to be able to operate a temporary service (B. Harris, personal communication, August 2017). Standard operational procedures exist whereby a survey of wharf damage would be carried out by the harbour master (two personnel on-island) to determine whether the wharf would be safe to use following impact and to make decisions around the use of the wharf (Chatham Island Harbour Master and Ports Officer, personal communication, August 7, 2017). There is an oil spill plan in place. Depending on the size, fuel type, and predicted dispersion a decision would be made as to whether external assistance from the Maritime Safety Authority (MSA), and their resources (spill crew, booms and skimmers) would be required (CIC, 2008).

Repair of the infrastructure where the cargo and larger fishing vessels berth at Waitangi wharf, the fisherman's wharves, and the fuel lines would be prioritised. There is on-island capability to repair superficial damage to wharves, timber and piles using limited stocks. Superficial damage to tanks and pipelines may also be repairable by welders. Damaged fishing vessels or moved containers would require towing to the shore or lifting by a crane (but there is no resident crane on-island) and/or forklifts. There could be delays in removing damaged vessels due to insurance and owner decisions, but these are usually made safe to minimize further damage to the vessel or other assets.

External assistance and resources from off-island would be required if the wharves sustained structural damage, for example, if new pipelines or bowsers were required or if sedimentation of the dredged area or bathymetric changes occurred (would need to survey changes). If large vessels could not berth, resources could be ferried into the harbour by smaller vessels or landed on the beach using a barge. There may be redundancy in having two wharves, if the main wharf is damaged. The smaller wharf structure, the fisherman's wharf, may be able to remain open for smaller vessels. (B. Harris, personal communication, August 2017). They would adapt to the situation until time when repairs are made to the main structure (with external assistance from the New Zealand Government). As B. Harris noted, the Chatham Island community tends to band together to prioritise actions, getting things done and worrying about how you meet that cost later (personal communication, August 2017).

Flower Pott Wharf

Flower Pott wharf services approximately 50 residents on Pitt Island. Flower Pott is also an open sea environment, and has been damaged multiple times by storms in the past (Chatham Island Harbour Master and Ports Officer, personal communication, August 7, 2017). The wharf was reconstructed in 2014 (MWH, 2013), a $4.7 million dollar project involving: the construction of a new wharf, quay, stockyard on re-claimed land, and re-constructing the breakwater, barge slipway and cargo shed as well as a 25,000 litre underground diesel tank (MWH, 2013; Chatham Island Harbour Master and Ports Officer, personal communication, August 7, 2017). Pitt Island has a barge that transports goods from the ship to the wharf (B. Harris, personal communication, August 2017). All of these components are exposed to tsunami hazard.

Flower Pott Wharf was destroyed in the 1924 tsunami event and Cyclone Pam (2015) caused considerable damage, costing $1.8 million in repairs (Table 2.1; Pennington, 2017). The New Zealand Government then announced a $3.5 million investment into complete works for the Pitt Island Wharf resilience programme on the Chatham Islands (Dunne, 2017). This work is currently under way (Chatham Island Harbour Master and Ports Officer, personal communication, August 7, 2017), thus configuration of wharf components may change compared to Figure 5.6.

Figure 5.6. Pitt Island wharf during construction in 2014 before the wharf was damaged in 2015 by a series of storms. Courtesy of Celine Photography (2014).

Owenga Wharf

Owenga wharf is a straight, piled structure with a boulder rip-rap sea wall (Figure 5.7). The wharf carries a fuel pipeline to service fishing vessels and electricity to service a light. The fuel pump is located off the wharf, on reclaimed land and the fuel tank sits above the wharf on a hill. Some fishing vessels are launched off the beach and towed to higher ground most nights (due to insurance reasons). Owenga wharf is susceptible to strong easterly weather, known to shipwreck vessels and wash boats off their trailers on the beach (Chatham Island Harbour Master and Ports Officer, personal communication, August 7, 2017). Owenga was impacted in the 1868 (sourced from South America) and 1924 (unknown local source) tsunami; boats were washed away in both events (Table 10).

Figure 5.7. Owenga wharf structure, sea wall and launch beach with fishing vessels on their trailers.

Kaingaroa wharf

Kaingaroa wharf (Fig. 5.8) services the fishing settlement at Kaingaroa. The wharf is deemed unsafe but is still being used. It is currently in the process of changing ownership. The Kaingaroa wharf facility contains a slipway and a straight, piled wharf structure which is connected to a decommissioned fish processing factory. A fuel line and electricity cable are attached to the wharf.

At Kaingaroa fuel is pumped from an underground tank onto the wharf. Approximately two hundred litres of fuel sits in the pipe at any one time, thus has potential to spill during a tsunami if the pipe is damaged (Chatham Island Harbour Master and Ports Officer, personal communication, August 7, 2017). Kaingaroa wharf infrastructure has been damaged by tsunami in the past. The 1924 event damaged the freezer works and intake pipes and washed fishing vessels away. A boat was also washed away in the 1868 event (Table 1.2).

Figure 5.8. Kaingaroa Wharf.

Port Hutt wharf and Jetty

There are two, privately-owned wharf structures in Port Hutt, a small wharf (Figure 5.9) and a jetty. Both are structurally impaired (Chatham Island Harbour Master and Ports Officer, personal communication, August 7, 2017). There are two operational fishing vessels, one is tied to the wharf and one gets launched off the beach. There are two non-operational boats swinging on moorings and one large shipwreck sitting in the harbour. There is no fuel line although the factory has fuel storage. The CIET tanker travels to Port Hutt once or twice a month to fill the tanks, depending on productivity and consumption (Chatham Island Harbour Master and Ports Officer, personal communication, August 7, 2017; B. Harris, personal communication, August 2017). Considering that the wharves are already structurally impaired, a tsunami may cause considerable damage to both structures. The non-operational vessel and shipwreck could move and cause damage (Chatham Island Harbour Master and Ports Officer, personal communication, August 7, 2017).

Figure 5.9. Right: Assoc. Prof. Tom Wilson and Prof. David Johnston gazing out to sea on Port Hutt Wharf. Left: Non-operational vessels.

5.4.1.1.2.7 Roads and Bridges

Roads and bridges (Fig. 5.10) are critical infrastructure that provide access to townships on the Chatham Islands. They also often provide access to carry other lifeline networks including electricity, communication cables and pipes. The road network is mostly gravel (approximately 158 km), with some sealed roads (approximately 12 km) in the main townships of Waitangi, Owenga and Kaingaroa. The rest are un-metalled lime or dirt tracks (15 km) (based off LINZ road shapefile, updated Feb 2018). Bridges cross tidal creeks and rivers on Chatham and Pitt Islands. Most are single span timber bridges with metal or steel girders (with the exception of Waitangi bridge which is multispan, and a few single culvert bridges).

5.4.1.1.2.8 Vulnerability and Interdependencies

Roads and bridges are vulnerable to tsunami impact (Appendix 2.1.2.3.1). Coastal Chatham Island roads have a large number of culverts and may be susceptible to washout where culverts are located (Figure 5.10; Horspool and Fraser, 2016). During cyclone events or heavy rain on the Chatham Islands, the fine aggregates are washed from the gravel roads (due to flooding of roads by rain water or high lake levels) and they become dangerous to drive on (likened to driving on porridge) until they dry out (O. Pickles, personal communication, August 3, 2017). This may occur following tsunami inundation and/or ponding.

Cyclone Pam caused considerable damage to the Shelly Beach Culvert Bridge during its construction. It is likely to be vulnerable to tsunami impact. Some bridges are also old (including on Pitt Island) and may be more vulnerable to tsunami impact (Chatham Island Harbour Master and Ports Officer, personal communication, August 7, 2017; B. Harris, personal communication, August 2017).

Waitangi Bridge is the most critical bridge. It provides the South Coast and most of the Waitangi township with access to other parts of the Island. This has critical implications for distribution of emergency services as the bridge connects the EOC, hospital and police with the fire brigade, ambulance bay, evacuation centre and airport. Waitangi Bridge also carries potable water and communications. Distribution of their services is dependent on the structural stability of the bridge. Other bridges provide access to other settlements, some carry communication infrastructure. Low elevation bridges (below the 20m topographic contour) provide access to Owenga (Shelly Beach Bridge and Hawaiki Creek Bridge), the South Coast (Awamata Stream Bridge and Tuku Bridge) the airport (Waitamaki Creek Bridge) and Port Hutt (Whangamoe Bridge). On Pitt Island there are two low elevation bridges that provide access to residential areas.

5.4.1.1.2.9 Capacity and Operational Plans

Operative plans are in place to strategically relocate key equipment required to repair/rebuild roads and bridges during a tsunami warning, provided there is warning, and there is sufficient time to do so (O. Pickles, personal communication, August 3, 2017). Following tsunami impact, a damage assessment would be conducted for transportation infrastructure. Provided roading equipment had been relocated, roads may be patched or temporarily rebuilt using available resources and on-island metal (O. Pickles, personal communication, August 3, 2017). People on the island have four wheel drive vehicles. If creeks are shallow crossing may be achievable, but emergency vehicles may not be able to cross (B. Harris, personal communication, August 2017).

Figure 5.10. Roads and Bridges on the Chatham Islands.

5.4.1.1.3 Energy

5.4.1.1.3.1 Electricity

Electricity on the Chatham Islands is generated by five diesel generators (gensets). Electricity is generated at 11 Kv on the main grid which services Owenga, Waitangi, the South Coast, Te One and the Airport with a total of 219 customers (Figures 5.11 & 5.14). Electricity is distributed mostly via overhead lines (50 km) with underground cable (20 km) from Waitangi to the South Coast and in Kaingaroa (separate network) which has joiner boxes for each household. Transformers step down the voltage from 11 Kv to either 230 V for household use or 415 V for commercial/higher use. Wind turbines have been installed at Owenga but due to mechanical and maintenance issues, have produced a limited supply. A hydro generation plant has also been proposed. Total diesel consumption is approximately 62,000 L / month to generate electricity for the main electricity grid (slightly higher consumption rate than usual due to activity of building Waitangi Port). There is higher demand on the main electricity network during winter thus higher consumption of fuel.

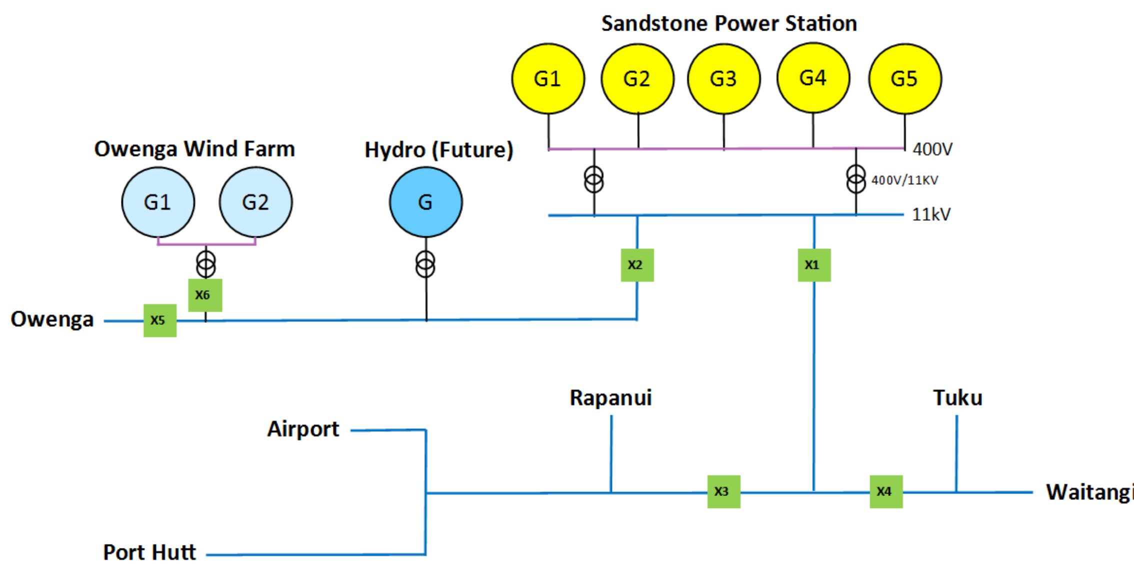

Figure 5.11. Conceptual diagram of the Chatham Island electricity network.

Other satellite generators provide electricity to Kaingaroa, Port Hutt and Pitt Island. Residents out of range of these sources own generators, or have solar power, wind power, small hydro generators or a combination thereof.

Figure 5.12.Electricity network components. Top Left: generated electricity at Sandstone Power Station. Top Right: underground network fuse box/transformer. Bottom Left: Overhead transformer. Bottom Right: Impacted power pole on the Chatham Islands. Retrieved from CIC (2018).

5.4.1.1.3.1.1 Exposure Vulnerability and Interdependencies

The power station is located on high elevation, in the safe zone (tsunami evacuation maps, Appendix C). Exposed assets include power poles in low lying areas, underground cable in low lying areas, cable attached to bridges, transformers and insulators. Power poles on the Chatham Islands are standard wooden stock. They are designed for wind loading and to break during car crashes but are not designed for tsunami impacts (B. Harris, personal communication, August 2017).

The biggest vulnerability for mains power electricity is security of supply of diesel. If there is no diesel there is no electricity (I.Sanson, personal communication, August 9, 2017; B. Harris, personal communication, August 2017). There is no alternative power source powerful enough to supply the whole grid if the power plant gensets lose function. Replacements would be required from off-island. Although some facilities may have back-up generators, these are subject to fuel supply limitation and cannot be used to power the whole grid (I.Sanson, personal communication, August 9, 2017). The most vulnerable part of the network to the natural elements is the South Coast and coastal areas where there are higher corrosion rates (salt water). Other parts of the network are regularly maintained (I.Sanson, personal communication, August 9, 2017). Occasionally storms cause disruptions to the power network if there are very high winds or if trees fall on the lines, but most disruptions are caused by vehicle crashes into power poles, faulty transformers, swans strike and possums (B. Harris, personal communication, August 2017).

Electricity generation is dependent on fuel supply. The communication, water and sewage networks are all dependent on electricity therefore repair and remittance of this network would be a priority following tsunami impact (I.Sanson, personal communication, August 9, 2017). There are also dependencies within the network. The reticulated nature of the network means that if one pole is impacted, the rest of the reticulation line beyond that damaged unit will not have live electricity.

5.4.1.1.3.1.2 Capacity and Operational Plans

There is no tsunami response plan for the electricity network, but standard operational procedures exist around health and safety, impact and reinstatement of power. If any part of the network is impacted, the system automatically shuts down (B. Harris, personal communication, August 2017). However, sections of the network are able to be isolated and turned off (isolation points are represented by the green boxes in Figure 5.11) remotely from Sandstone Power Station (a potential precautionary measure that could be taken during a tsunami warning). Roads and streets can also be switched off manually (Maipito Rd, Hospital Rd, Tuku Rd, North Rd, Rapanui Rd) (I.Sanson, personal communication, August 9, 2017).

On-island electricity resources (spare parts) include approximately 1km of line, 21 poles, and 2-3 small transformers. Components could also be “borrowed” from smaller streets and roads for the greater good. If poles are just on a lean, they can be straightened using a hiab truck (or a digger if it’s wet. Hiabs and diggers are available on-island). Issues occur if the poles completely fall over or break where the line and pole may need replacing (Figure 4.12). The underground network is much harder and takes longer to fix than the overhead network. Extra resources and staff may be needed depending on the extent of the damage. External staff would require knowledge of the Chatham Island network. A pre-existing relationship exists with a company in the Coromandel who obtained knowledge of the Chatham Island network during past maintenance projects.

There are some back-up generators on the island: Police, Hospital, Fire Brigade, radio station, airport, fish factories and there are a number of personal generators. However, these will not generate enough power to supply the whole grid. There have been conversations around getting a genset which could be portable and could be strategically located (provided there was sufficient warning) to provide energy to the grid (potentially the new emergency management center) (B. Harris, personal communication, August 2017) (I. Sanson, personal communication, August 9, 2017).

5.4.1.1.3.2 Fuel

Fuel supply and infrastructure are also critical on the Chatham Islands. Fuel is essential for day-to-day operation on the Chathams. Diesel, petrol and gas are transported via cargo ship from Timaru or Napier to Waitangi. Petrol is required for dive boats, some cars, and household appliances such as lawn mowers and chainsaws. Petrol arrives in drums, or silver dolphins (10,000 L certified self-bunded tanks) and can be purchased from two outlets in Waitangi. Gas is used on the island for cooking and for hot water in some houses. Gas arrives in large canisters and can be purchased from two outlets in Waitangi.

Diesel is the most critical fuel and is pumped off the ship into bulk storage tanks (180,000L horizontal tank and 80,000L vertical tank) located in Waitangi harbour at sea level (Figure 5.13), or into mobile fuel tankers. The bulk diesel tanks service the wharf for fishing vessels, and the fuel tankers distribute diesel to fuel stations, satellite electricity generators and other remote customers. In total, the on-island diesel capacity is approximately 400,000L if all tanks are full (for all uses) and usually, there is approximately one month's supply on-island.

There are two fuel stations in Waitangi with underground tanks. One sells both petrol and diesel, the other just diesel. Owenga has a bulk facility that services the wharf.

Kaingaroa has a bulk fuel facility which services the satellite generator, fuel pump for vehicles and the wharf for fishing vessels and has a maximum of 14 days of storage. This bulk facility is topped up fortnightly and the township contacts the fuel provider when they have a day or two's supply remaining. Port Hutt and Waitangi West have limited bulk storage tank for the area. They make their own arrangements.

Fuel is transported to Pitt Island from the cargo ship via a barge and stored in underground tanks at the wharf. Pitt Island has sufficient fuel for filling up fishing vessels, generators, and vehicles for 6-8 weeks when full. Pitt Island is isolated thus is regularly serviced with fuel so that they are not in danger of running out.

Figure 5.13. Fuel infrastructure. Top left: Diesel pumps at one of the petrol stations in Waitangi. Top right: bulk diesel tanks on the foreshore in Waitangi. Bottom: Satellite diesel storage at Sandstone Power Station.

5.4.1.1.3.2.1 Exposure Vulnerability and Interdependencies

The most exposed assets are the bulk fuel tanks near the wharf in Waitangi harbour and the wharf pipelines which may be vulnerable to tsunami impact (B. Harris, personal communication, August 2017). The bulk fuel tanks are both in good structural condition. The concern would be in the connections (pipes and bowsers), access to the tanks and any damage from debris. The horizontal bulk tank is designed as a barge thus buoyant forces may cause the tank to float. Underground fuel tanks and fuel lines at Kaingaroa wharf, Pitt Island Wharf and at fuel stations may also be exposed if the wharves are damaged or if the tsunami causes erosion (B. Harris, personal communication, August 2017).

The fuel network would be most vulnerable when depleted and awaiting restock (B. Harris, personal communication, August 2017). One of the petrol stations is also on low lying land (3.5 m elevation) in Waitangi close (100 m) to the sea.

Fuel is transported to the Chatham Islands by ship from Timaru or Napier and depends on the ability of the vessel to berth at Waitangi harbour. Once the fuel arrives there are dependencies in the transportation network. Access to the wharf is essential for offloading fuel and roads and bridges are required to distribute fuel. The fuel network also requires electricity to operate the pump at Waitangi Wharf (to service the wharf) and other pumps at Owenga, Pitt Island and Kaingaroa wharves.

5.4.1.1.3.2.2 Capacity and Operational Plans

Emergencies have been declared in the past when the island has run out of diesel supply. There is a good relationship with the fuel supplier and the community is very aware of the challenges of the fuel network, people also store their own supplies (B. Harris, personal communication, August 2017).

The Sandstone Power Station has satellite fuel storage (supply for 10 - 12 days' of generation) which is kept as full as possible, providing some redundancy if the bulk fuel tanks are damaged (B. Harris, personal communication, August 2017). There is also storage at the communications exchange, fish factories store some fuel and the hospital has a supply for their back-up generator. The last thing that the Island will run out of is diesel. Petrol and gas would deplete first (I. Sanson, personal communication, August 9, 2017).

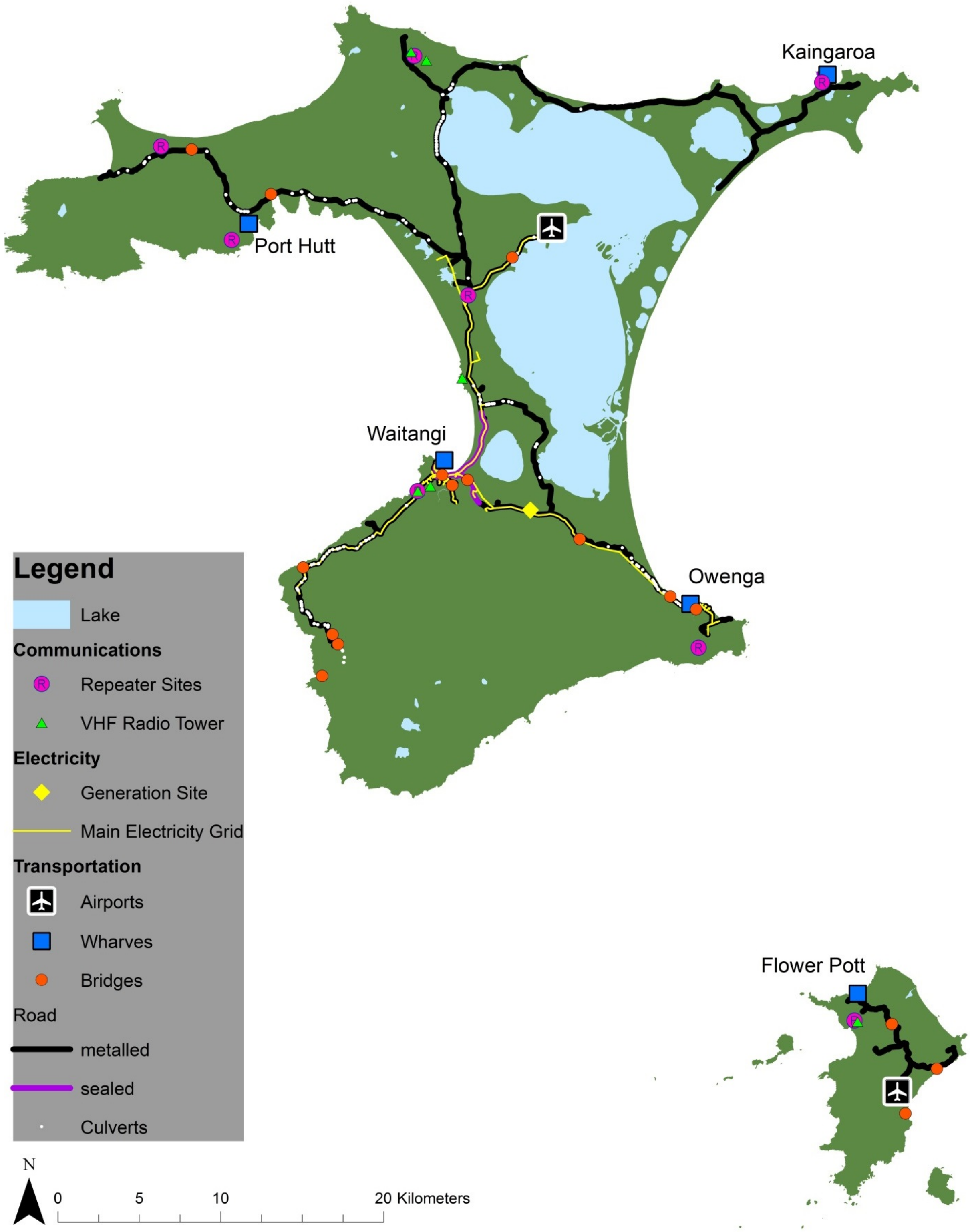

Figure 5.14. An overview of communications, electricity and transportation networks on the Chatham Islands.

5.4.1.1.4 Water

5.4.1.1.4.1 Potable water

Potable water in Waitangi is supplied by a bore on Tikitiki Hill (Figure 5.15). Most households and commercial properties in Waitangi rely on this water system and supply. The water is treated at site (chlorinated and softened) then pumped through pipes into reservoir tanks located at the Met Station (1 km from the source). There is approximately 2 days storage in total in 4 x 30,000 L tanks. Water is then reticulated throughout Waitangi with laterals but constrained by one pipeline (water gravity feeds in one direction).

Potable water in Kaingaroa is pumped from Lake Rotorua through pipes to a treatment facility on a hill behind the township and is then gravity fed to houses. There is also a bore in Sandstone. Other residents have personal or shared rain water tanks or bores.

5.4.1.1.4.2 Wastewater/Sewage

There is no storm water infrastructure on the Chatham Islands except a limited system in Waitangi. The sewage system in Waitangi is gravity fed to a collector tank (6.5 m elevation proximal to the sea) (Figure 5.15) where it is pumped to a treatment facility and sprayed on farmland. Most other residents have septic tanks.

5.4.1.1.4.3 Water Networks Exposure, Vulnerability and Interdependencies

- The most exposed assets are the water pipe across Waitangi Bridge and the sewage collection tank.
- In summertime (and nowadays encroaching into spring and autumn) people need to cart water from the town supply over a period of 2 - 3 months when it’s dry. In summertime the bore is pumping 24/7, just keeping up with demand. If a tsunami occurred during summer the water supply on Chatham Island would be limited/low. The Waitangi bore is increasingly being depleted and a replacement bore site is required for the near future.
- Water and sewage are dependent on electricity (and fuel supply) for pumping facilities, although houses may receive water through gravity flow.

5.4.1.1.4.4 Water Networks Capacities and Operational Plans

There are some houses still connected to rain water tanks in Waitangi. There may be capacity to connect other houses to these tanks, provided there is enough rain. There is a main valve above the bridge. The communications manager closes the valve during a tsunami warning to save the reservoir from being drained if the bridge is damaged.

Figure 5.15. Water infrastructure components. Top Left: water and communications attached to Waitangi Bridge. Top Right: Waitangi Bore. Bottom: Sewage collection tank and pump.

Figure 5.16. Potable water and sewage networks in Waitangi.

5.4.1.2 *Hotspots, Pinchpoints and Criticality*

The network characterization above (informed by infrastructure manager's expert opinion and field surveys) helped to understand infrastructure interdependencies for Chatham Islands. A field survey was not completed for Pitt Island due to time and budget constraints thus an informed hotspot, pinchpoint and criticality analysis was not completed for this location.

Chatham Islands hotspots include:

- bridges which communications, electricity, transportation and/or water depend on,
- wharves which transportation, water, electricity and fuel networks all depend on,
- Inia William Tuuta Memorial Airport which transportation of goods and services depends on but also requires electricity, communications, and water to operate.
- Sandstone Power Station which electricity, water, sewage, communications, transportation, and fuel depend on.
- Bulk fuel facilities which electricity, communications and transport depend on but require electricity and transportation to operate.

Chatham Islands pinchpoints include:

- Electricity - Sandstone Power Station, all power poles along the reticulated network especially along critical or important network lines (Figure 5.17) as well as transformers.
- Transport - wharves and bridges, most residents have 4wd vehicles, if roads are damaged could presumably drive around the damaged section.
- Fuel - the bulk storage facility, fuel pumps and pipelines.
- Water (for both potable and sewage) - pumps and the water pipe across Waitangi Bridge as well as the sewage collection tank.
- Communications - the satellite, central exchange, signal repeaters and any points along the landline cable, especially along critical or important network lines.

There is 29.22 km of critical network line (essential for preservation of life) on Chatham Island (Figure 18). The critical line runs from Sandstone Power Station to Waitangi (to Tikitiki Hill and also extends along the South Coast road to the communications exchange) then to the airport. Networks along this line (transport, electricity and communications) service the hospital, ambulance bay, fire brigade, EOC, the designated evacuation centre, airport communications and water.

There is 82.45 km of important network line (important for economic continuity as well as social and cultural welfare) on Chatham Island. This line services key assets including fish factories, community halls, wharves, schools and sewage infrastructure components.

There is 19.33 km of moderate local influence line and 50.50 km of minor local influence line.

Figure 5.17. Hotspots and pinchpoints in Waitangi with locations of emergency service facilities.

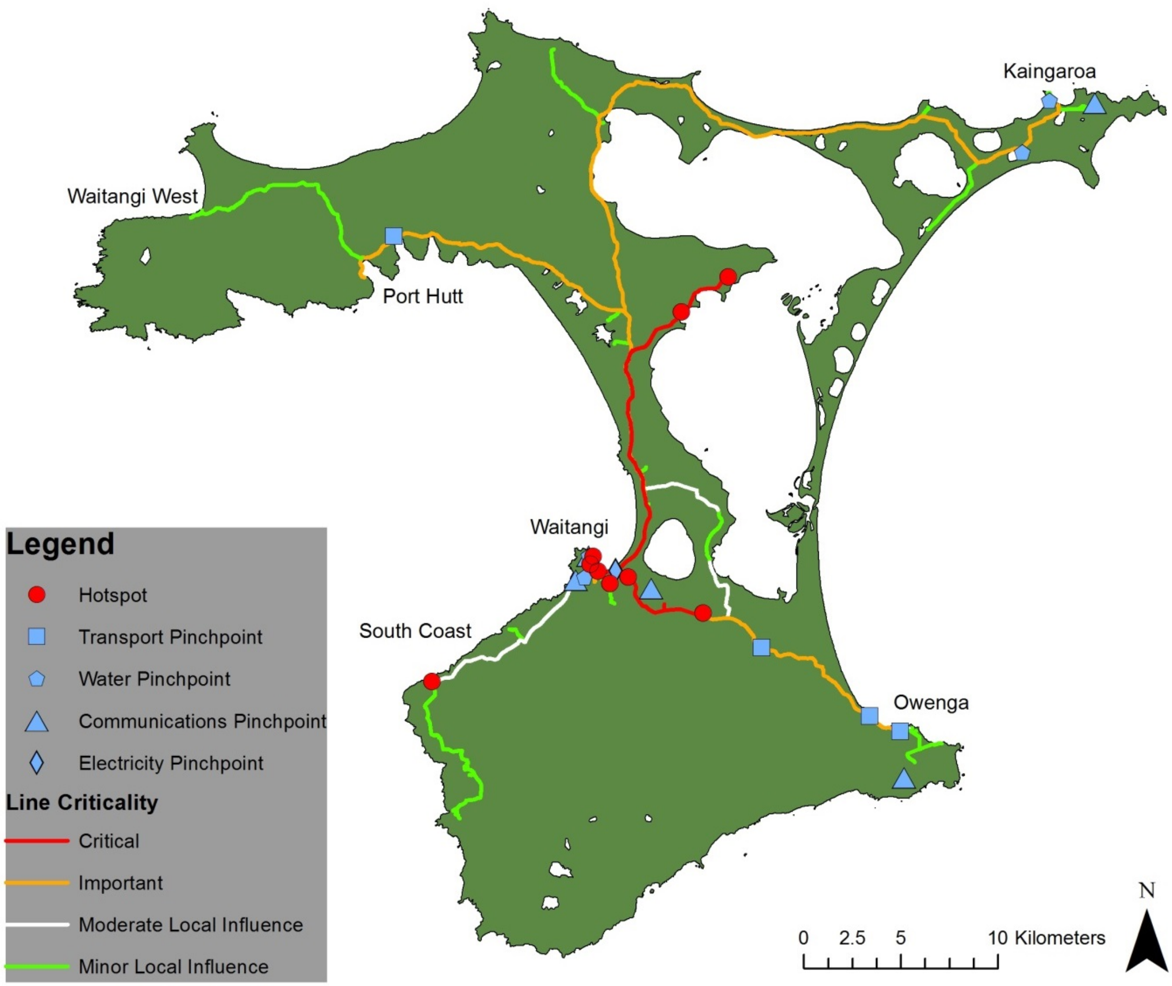

Figure 5.18. Chatham Island hotspots, pinchpoints and network line criticality.

5.4.1.3 Exposure to Hazard Model

Exposure of infrastructure components to the hazard model (developed in Chapter 4) is presented in Tables 5.6 and 5.7. These are measured in kilometer lengths for network assets (such as water pipe) and counts for network nodes (such as fuel tanks).

The transportation and electricity networks have the largest number of assets exposed to the hazard scenario. All wharves, 10 bridges, and 17 km of the road network and 13 culverts are exposed to inundation. Most of the road exposed is gravel. Electricity assets are also exposed, 66 power poles in total are inundated by some depth potentially exposing 3.9 km of overhead line and 6 transformers; 1.86 km of underground electricity cable is also exposed to inundation.

Substantial amounts of fuel infrastructure are exposed to the hazard model. Three underground tanks and three above-ground tanks are exposed to inundation and 670 m of fuel pipeline is exposed to tsunami inundation of ≥ 2 m, indicating potential spill of fuel into Waitangi, Kaingaroa, Owenga and Flower Pott habours.

In Waitangi, water infrastructure is also exposed, including the sewage collection tank and 2 km of potable water pipeline (Figure 5.19). The potable water network in Kaingaroa was not included in the scenario as it was not identified until after the workshops. Participants in the workshops (Chapter 6) identified the missing network and it is estimated that another 300 m of pipeline may have been exposed to the 0.5-1.0 m zone (Google Earth). Privately owned water tanks were not included in this study due to time constraints involved in accessing residents' properties and private land.

Phone line exposure was only assessed in Waitangi due to time constraints involved in the field survey. In Waitangi 3.27 km of phone line is exposed to inundation. However it is likely phone cable is also exposed in Kaingaroa, Port Hutt and Owenga.

Table 5.6. Exposure of Chatham Island infrastructure assets to a hazard scenario.

Inundation Depth (m)	Roads (km)		Overhead Electricity Line (km)	Buried Electricity Cable (km)	Phone Line (Waitangi) (km)	Potable Water (Waitangi) (km)	Fuel Pipeline (km)
	Sealed	Gravel					
0.0 - 0.5 m	2.55	10.45	1.58	0.62	0.54	0.11	0
0.5 - 1.0 m	0.38	1.83	0.65	0.56	0.69	0.23	0
≥ 2.0 m	0.79	1.25	1.66	0.68	1.53	1.67	0.67
Total	3.72	13.52	3.89	1.86	3.27	2.00	0.67

Table 5.7. Exposure of Chatham Island infrastructure network nodes to a hazard scenario.

Inundation Depth (m)	Wharves	Bridges	Power Poles	Transformers	Culverts	Fuel Storage Tanks (BG)	Fuel Storage Tanks (AG)	Sewage Tank and pump
0.0 - 0.5 m	0	1	28	4	9	0	0	1
0.5 - 1.0 m	0	6	14	1	4	1	3	0
≥ 2.0 m	6	3	24	1	0	2	0	0
Total	6	10	66	6	13	3	3	1

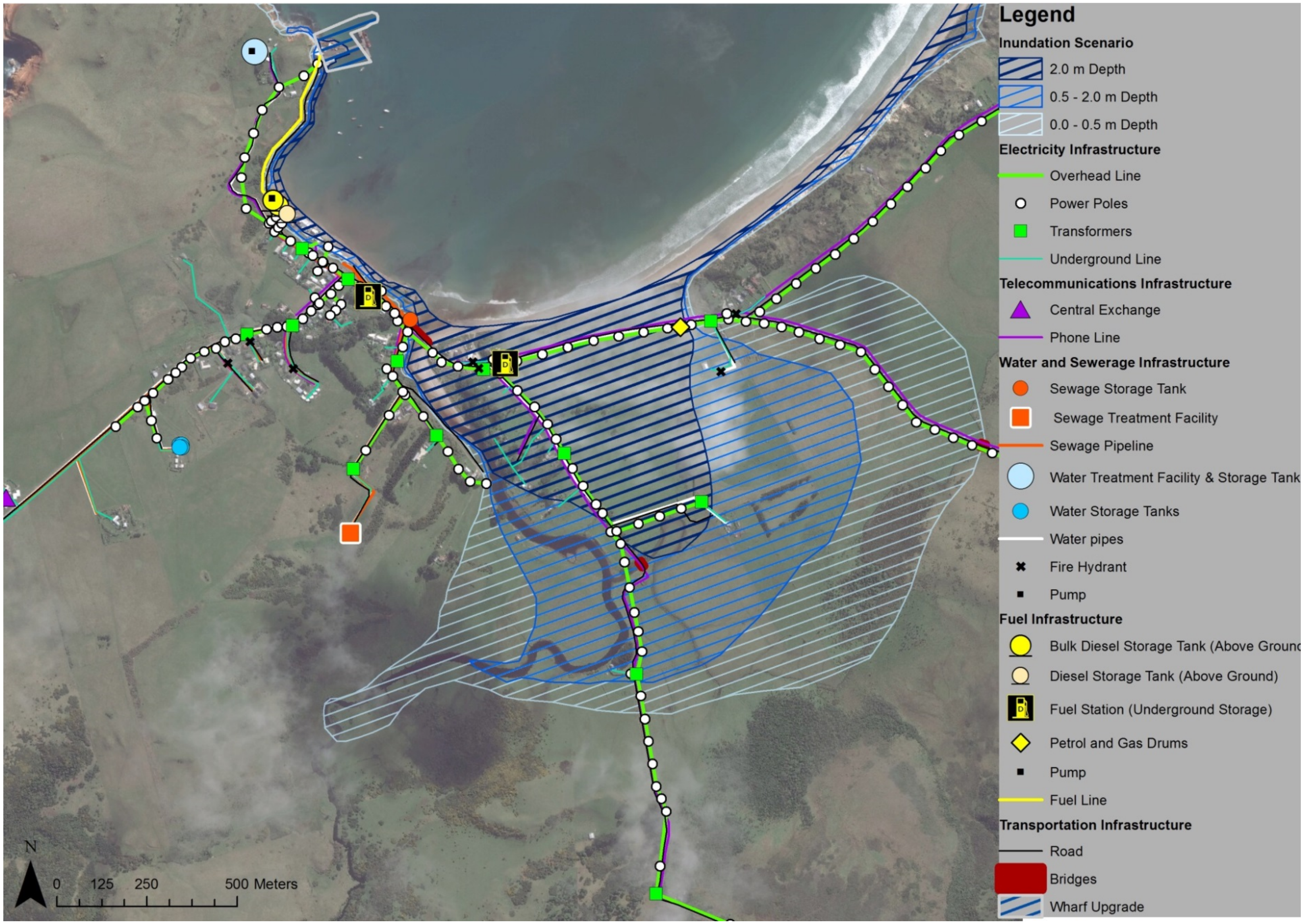

Figure 5.19. Hazard and infrastructure inventory overlay in Waitangi.

5.4.2 Vulnerability and Impact

As stated in 5.3.4, a table was generated relating the probable damage description provided in Williams' (2016) damage matrix to a damage state to then infer a level-of-service for each infrastructure asset exposed to the hazard scenario. These tables are referred to as vulnerability matrices. Table 5.8 shows the vulnerability matrix generated for bridges and is supported with Figure 5.20 which provides visual example for damage states. See Appendix F.2 for vulnerability matrices for roads, wharves, electricity components, communications components and water components.

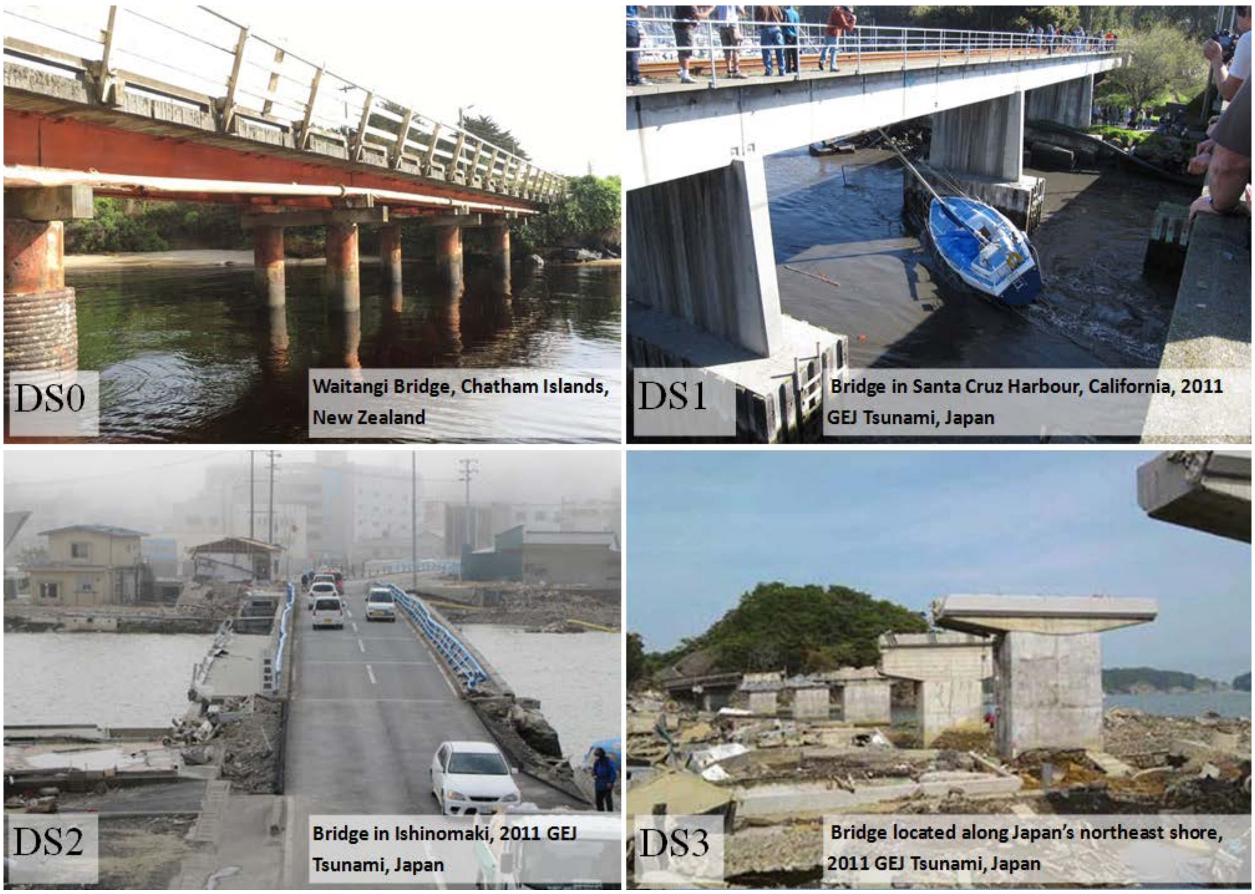

Figure 5.20. Examples of Bridge damage state. Top Left: Waitangi Bridge, Chatham Islands, DS0. Top Right: Bridge in Santa Cruz, DS1 following impact from 2011 GEJ Tsunami, retrieved from USGS, (2011). Bottom Left: Bridge in Ishinomaki, DS2 following impact from 2011 GEJ Tsunami, retrieved from MRP Engineering, (2011). Bottom Right: Bridge at DS3 following impact from 2011 GEJ Tsunami, retrieved from Bravo et al., (2015).

Table 5.8. Vulverability matrx for bridges relating damage type to damage state to leve- of-service. Derived from Horspool, 2016; Williams, 2016 and Robinson et al., 2014.

Damage Type			**Damage State**		**Level-of-Service**	
Flow Depth (m)	**Probability of damage**	**Description**	**Metric Value**	**Description**	**Metric Value**	**Functionality State**
0	None	No damage	DS0	Promptly usable without repair or clean up	LS0	Full service, operating as normal
<0.5	Negligible-Low	Superficial debris strikes	DS1	Minor damage, often impacts to the superstructure. Bridge fit for purpose without immediate repair	LS1	Full service, operating as normal, needs minor repairs
0.5-2.0	Medium	Some bank/abutment/wingwall erosion, superficial debris strikes , sediment deposition, scour of footings, corrosion, washout of light timber structures	DS2	Some structural damage, possibly usable after repair and clean up. Requires moderate-major repairs	LS2	Partial access – operating under speed and load restrictions.
>2.0	High	Debris and sediment deposition, erosion of adjoining banks/abutments/wingwalls, loss of signage and markings, side barriers bent or sheared, debris strikes, scour of footings, aggradation of waterway, widening of waterway, separation of deck from footings, lateral distortion of super structure, separation of girders, washout of superstructure, corrosion, damage to utilities across bridge	DS3	Complete washout of superstructure, mostly irreparable structural damage, require demolition and rebuilding	LS3	No access, not operational.

5.4.3 Impact Scenario

Overlaying the hazard model (e.g. inundation model) and infrastructure inventory (e.g road network etc) allowed assessment of how exposed each asset was to tsunami inundation (e.g. how many kilometers of road are inundated by > 2 m or how inundation an asset is exposed to e.g. 4 m bridge) in each depth parameter. The vulnerability matrices (Table 5.8 and in Appendix F.2) were then used to derive levels of service. Full explanations are provided below for each settlement and are illustrated in Figures 21 & 22.

5.4.3.1 Waitangi

- Waitangi Wharf is DS2, some X-blocs are dislodged, rocks in the harbour have moved and sedimentation has occurred in the berthing area. The fisherman's wharf is usable.
- The fuel pipe is damaged at connection points, bowsers have been damaged, tanks have suffered debris impacts and the pump is nonoperational. The fuel station is inundated, there is damage to the underground tanks and pumps. There is fuel spill in the harbour.
- Waitangi Bridge is DS3, and LoS3; the bridge is not operational.
- Damage to Waitangi Bridge has resulted in loss of water and communications services east of the bridge.
- Power poles in low lying Waitangi are DS3, resulting in loss of electricity service throughout Waitangi and to the South Coast.
- The sewage collection tank was inundated and the pump is non-operational, debris impacts and scour have resulted in leakage from the tank.

5.4.3.2 South Coast

- Access past Durham is restricted by damage to Awamata Bridge which is DS3 with no access.
- The phone and electricity line is severed at Awamata Bridge resulting in loss of landline service and electricity past Durham.
- Access also is restricted due to damage to Tuku Bridge which is DS2 and operating at partial service (load restrictions).

5.4.3.3 Kaingaroa

- Access to Kaingaroa is impaired due to sections of the North Rd being DS2 and LoS2, the road has been inundated, fine aggregates have been washed away and there is ponding on the road - likened to driving on porridge. Access from Kaingaroa to Kaiwhata/Kaingaroa Station is also impaired due to damage to the causeway (DS3) complete washout with no service.

- Kaingaroa wharf is DS3 and LoS3.
- The electricity generator shed is exposed to inundation (<0.5 m) as is the underground electricity cable and fuse boxes. Thus there is no electricity service in Kaingaroa
- The land line is damaged (DS3) and there are no landline communications in Kaingaroa.

5.4.3.4 Owenga

- Access to Owenga is impaired by damage to Shelly Beach Culvert (operating at partial service), damage to sections of the road (partial service) and damage to Hawaiki Bridge (no service).
- Owenga wharf is DS3 and LoS3, minor fuel spill in the harbour.
- The landline is severed at Hawaiiki Bridge thus no landline communication.
- 13 powerpoles and one transformer were subjected to 0.5 -2 m inundation thus Owenga has no electricity service.
- No internet due to loss of electricity.

5.4.3.5 Airport

- Access to the airport is impaired due to damage to Waikato Bridge, operating with partial service (light vehicles only) and ponding of water on the road (speed restrictions).
- The airport is DS1, the runway requires cleaning-up of sediment and debris before aviation services commence (planes can land or take off) and planes may need to be cleared of debris.
- Internal or external communication landline has no service due to damage in low-lying areas of Waitangi and damage to the cable at Waikato Bridge. VHF radio and satellite phones can be used for internal and external communications.

5.4.3.6 Pitt Island

- Flower Pott Wharf is DS3 and LoS3, major structural repairs are required before serviceability.
- Fuel spill into the harbour due to damage to underground tank connections and scour of earth fill around the tanks.
- Two bridges (Waipaua and North Head Bridges) are LoS3 restricting access to North Head and Glory Bay.

Loss of landline service and internet (due to loss of power) in this scenario means that all emergency services would be solely reliant on back-up fuel supplies as well as VHF radios and satellite phones for internal communications until external resources could arrive.

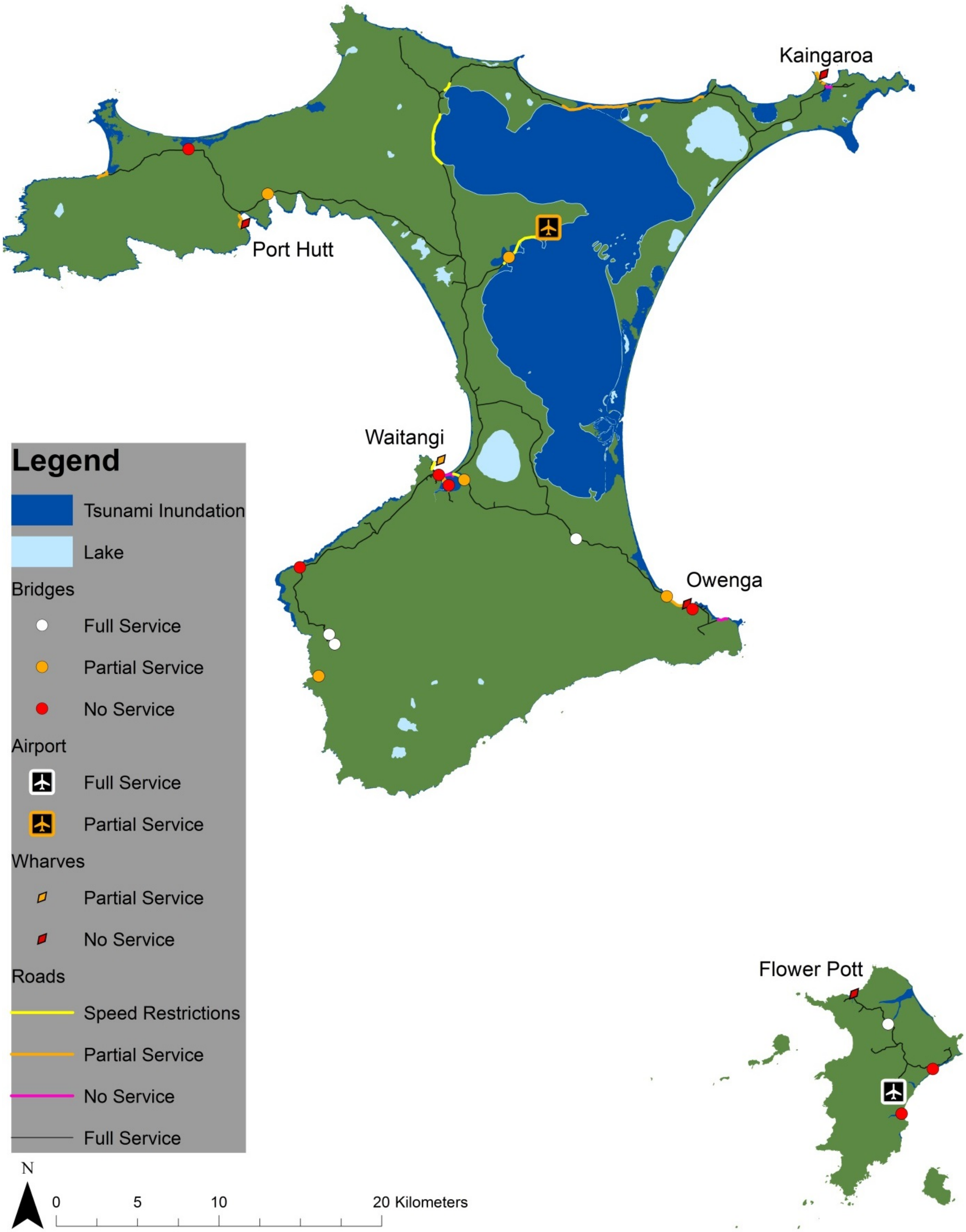

Figure 5.21. Levels of service of the transportation network on Chatham and Pitt Island.

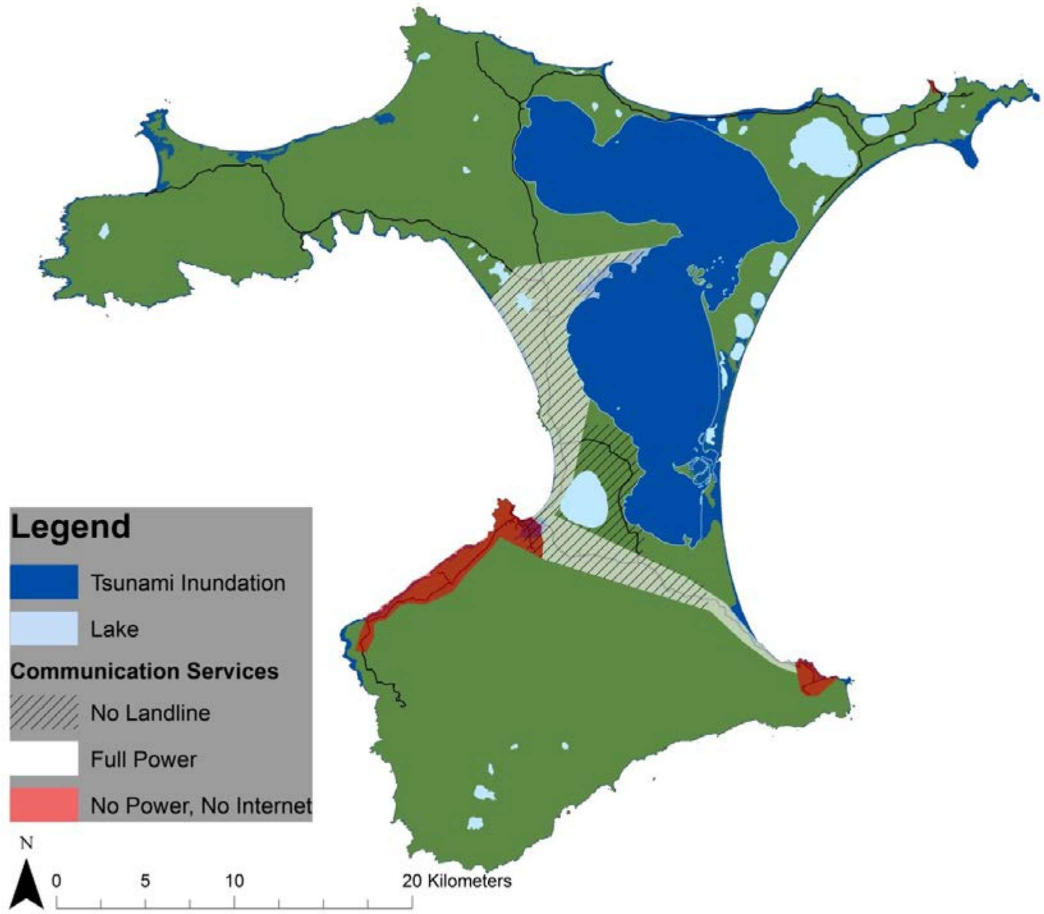

Figure 5.22. Levels of communications, electricity and internet service expected on Chatham Island.

5.5 Discussion

5.5.1 Methodology

Field surveys and interviews with infrastructure managers allowed development of a fairly comprehensive infrastructure inventory for energy (electricity and fuel), communications, water (potable and sewerage) and transport networks on the Chatham Islands. The inventory provides the first digital compilation of infrastructure networks on the Chatham Islands. This inventory (with further development to update and incorporate new components) could be used for future impact assessments on the Chatham Islands and will provide useful reference maps during scenario exercising, emergency responses or for planning future development.

Williams (2016) (who developed the vulnerability metric used in this study) carried out a tsunami impact assessment using a similar methodology but was limited by exclusion of network interdependencies.

Thacker et al. (2017) suggest that GIS tools such as a kernel density analysis can be used to locate hotspots and pinchpoints. However, in the present small setting, interviewing local infrastructure managers proved a successful approach to developing an understanding of infrastructure networks, component dependencies, interdependencies, and consequences of component failure which informed the impact scenario (a method also used by Robinson et al., 2015 and Orchiston et al., 2018 in the rural New Zealand context). Maps displaying interdependencies and criticality are the first for the Chatham Islands and provide useful insight for emergency management and asset security.

An innovative method was used to inform qualitative damage states and levels of service based on damage descriptions provided in Williams' (2016) matrix; which apart from efforts by Horspool and Fraser (2016), appears to be the first such resource in the DRR field of science. The table provides a bespoke "look-up" resource for the Chatham Islands based on empirical impacts, expert judgement by infrastructure managers and inferring the unknown. The same methods (literature review and expert elicitation) could be applied to develop a nation-wide 'tsunami impact to infrastructure' table for use in assessments where applicable fragility functions are not yet available.

5.5.2 Discussion of Results

This impact assessment incorporates a wider range of infrastructure types and components than that included in Thomas' (2017) exposure assessment. The results of the impact assessment (Sections 5.4.1-5.4.3) show that a significant amount of Chatham Islands infrastructure is exposed to potential tsunami impact (Tables 5.6 and 5.7) than previously assumed. This is both due to a larger inventory and due to incorporation of network interdependencies and criticality in the assessment.

There is an extensive amount of critical network line (29.22 km) on the Chatham Islands due to sparsely distributed key infrastructure components, sparsely located emergency service facilities (Sandstone Power Station, EOC Centre, central communications exchange and airport), lack of alternative lines and the reticulated (connected, dependent) nature of networks. The critical network line is exposed to tsunami inundation and this has serious implications for loss of essential services. In this scenario, tsunami impact on areas along the critical line resulted in loss of electricity, communications, some of the transport network and water in Waitangi. Based on the information provided in 5.4.1.1, during this scenario all emergency service facilities would be solely reliant on back-up fuel supplies to generate electricity for operation and will be reliant on VHF radios and sat phones for internal communications.

The important network line is more extensive than the critical line (82.45 km) as it provides for local businesses, schools, cultural assets and ports; its services are important for social and economic recovery. The important network line is exposed to tsunami inundation from this scenario resulting in loss of access to settlements which may have significant implications for distribution of resources. It is however noted, it is rare if a Chatham Island household does not possess a 4WD vehicle, and alternative tracks may be possible and passable by 4WD, ATV, horse or on foot.

Section 5.4.1.1 provides a summary and compilation of all infrastructure networks on the Chatham Islands, their interdependencies and key vulnerabilities to tsunami impact based on expert opinion provided by local infrastructure managers. Important information is contained in this Section on potential tipping points (point or situation when the on-island capacity to reinstate services is exceeded). This scenario likely exceeds the ability of on-island resources to reinstate the electricity and internal communications network. According to the scenario, 24 power poles and 2.2 km of line (line exposed to >2 m and 0.5-2 m depths, Tables 5.6 and 5.7) would need replacing, exceeding the on-island capacity outlined in Section 5.4.1.1.3.1.2. The scenario also impacts 3.27 km of landline cable, which probably exceeds the 'bits and pieces' available on-island (Section 5.4.1.1.1.2). However, during interviews with infrastructure managers, the resilience of Chatham Islanders and on-island ability to "make things work" (adaptive capacity) was a recurring theme (R. Phillips & B. Harris, personal communication, August 2, 2017; O. Pickles, personal communication, August 3, 2017). The results of the impact scenario only present immediate impacts and do not incorporate the likely adaptive capacity (e.g. ability to make things work). Identification of the moderate and minor local influence network lines will provide a useful decision making tool when network lines may need to borrowed to prioritise reinstatement of important and critical lines.

Based on the information provided in Section 5.4.1.1, the most problematic impacts included in this scenario would be:

- Washout of Waitangi Bridge hotspot with respect to distribution of resources, loss of water and communications infrastructure.
- Changes in harbour navigation and loss of berthing service for large vessels at Waitangi Port (another hotspot) for provision of external resources too heavy to be transported by air.
- Loss of Service from Owenga, Flower Pott and Kaingaroa wharves for inter-island transportation of resources and economic recovery (key pinchpoints in the transportation network).

- Impaired access to the airport due to damaged road and bridges in regards to transporting air-delivered cargo.
- Loss of service of bulk diesel facilities and fuel spills in harbours (hotspot).

It is anticipated that these impacts will facilitate interesting discussion during the participatory workshops (Chapter 6).

5.5.3 Limitations & Future Work

A number of limitations and assumptions are contained within this impact assessment; including in the hazard scenario used, in the methods used to assess exposure and to generate the vulnerability model which informed the impact scenario. Limitations and assumptions have been categorised in Table 5.9 to illustrate as to whether these may have led to underestimation or overestimation of impacts and resultant levels of service included in the scenario.

Despite the limitations outlined in Table 5.9, and regardless of whether the impacts are over- or underestimated, the scenario is fit for purpose for further use in this study during the participatory workshops. The scenario comprises a wide range of impacts on infrastructure and resultant levels of service that are possible, justifiable, and not too far-fetched to facilitate discussion around actions that could be taken to reduce these impacts. However, for the purposes of informing more accurate quantities of resources that may be required following a tsunami event, the model could be improved by:

- Capturing LiDAR data for both Chatham and Pitt Island to generate a high resolution DEM and remodeling hydrodynamic inundation scenarios to provide quantitative hazard parameters (depth and velocity) and less uncertain inundation extents.
- Detailed infrastructure asset surveys and incorporation of missing assets from this inventory, including assets located on private land (ideally by infrastructure providers who have the best knowledge of their networks).
- Modelling different scenarios and incorporating whether or not relocatable assets could be mobilized to safe areas prior to impact (e.g. a South American event vs a local tsunami).
- Facilitating a participatory impact scenario workshop with infrastructure managers and staff.
- Development of A-NZ specific quantitative vulnerability models for all infrastructural assets.
- Inclusion of regional impacts on sister ports (Timaru and Napier) to determine time delays in shipping external resources to the island

Table 5.9. Limitations and assumptions made in the methods used and their implications for the impact scenario in terms of underestimation or overestimation (indicated by blue coulumns).

	Assumption/limitation	**Implication for Impact Scenario**	
		Underestimation	**Overestimation**
Hazard	The inundation extents and associated depth have been informed by oral history, inundation models and are guided by topography. Limitations are associated with the above methods as discussed in Section 4.5.1. In summary the hazard scenario is simplistic, it has broad inundation depth bins and the spatial extents of these depths are only inferred.		
	Factors which control tsunami inundation flow direction, depth and velocity such as surface roughness or performance natural protection structures is not considered.		
	The scenario does not incorporate multiple inundating waves, and assumes static topography during inundation. In reality topography would change, for example, sand dunes and river banks may be eroded and result in land being inundated by subsequent waves.		
	The scenario does not include other tsunami parameters such as velocity and debris.		
Exposure	Not all assets are included in the exposure inventory. Due to time restrictions in the field survey and assets located on private property, GPS points were not collected for individual power poles (these were digitised on Google Earth 2015 imagery), fuse boxes and building inlets/outlets which are susceptible to impact.		
	Assets that were not collected by GPS were digitised using 2015 Google Earth Imagery, it is acknowledged assets may have since been removed or relocated. Exposure of the network is expected to change over time also changing exposure and risk.		
	Private property including fishing vessels, holding pots and fishing launches which could become debris entrained in the flow and potentially damaging to infrastructure assets were not included in the impact scenario.		

	A wealth of information is provided in Section 5.4.1.1 around exposed assets, opinions of network components that may be most vulnerable and on-island capacities to respond to impacts as well as potential issues that may arise in response in recovery (e.g. insurance involved in clean up processes). This information was a great advantage but not all of the information was incorporated due to time constraints. The information contained in Section 5.4.1.1. will be useful in future impact assessments.		
Vulnerability	The most applicable vulnerability metric for this study was Williams (2016) qualitative damage matrix, there are several limitations included in this approach. The first, is that it is qualitative and has broad inundation depth bins.		
	Only inundation is considered in the matrix, other hazard metrics not considered (e.g. velocity).		
	Construction standards of infrastructure are not considered within the damage matrix.		
	The damage descriptions for some assets are informed by low volumes of literature/observations.		
Impact	There are also limitations and assumptions involved in the methods used to derive damage states and to then infer levels of service. Damage states can infer LoS but LoS are dynamic and can change quickly depending on the capacity of infrastructure providers e.g. a port might be destroyed like Lyttleton after the Christchurch Earthquake but may be useable after minor readjustments. The levels of service provided in this scenario have tried to accompany these capacities by stating a LoS as well as what may be required to achieve serviceability e.g. LS2 but usable after minor repairs.		
	Levels of service do not consider all dependent/interdependent infrastructural assets or secondary impacts, for example a road may be passable, but culverts may be blocked by debris or damaged resulting in on-going flooding of the road affecting the serviceability.		
	The probabilities associated with the damage descriptions included in the vulnerability matrix were not considered in the impact model. Instead it was assumed the damage described would occur. This assumption was made as the probability of damage could not be translated directly to inform the probability of a damage state occurring nor the resultant LoS and there is no literature available to help inform these probabilities. Absence of probabilities allowed the impact scenario to be usable by the community. In the context of the workshop, stating that a road has a X probability of being passible would not be practical.		

5.6 Summary

This Chapter addresses the main objective to generate a credible tsunami impact scenario that overlays hazard, exposure and vulnerability information to identify areas of high exposure and vulnerability to create an impact scenario to be used to inform disaster impact reduction initiatives. Through this process, the Chatham Islands infrastructure network system design, interdependencies, vulnerabilities and capacity to function following tsunami impact were evaluated and the exposure inventory generated by Thomas (2017) was substantially improved.

The methodology used in this study demonstrates the value of expert judgement in determining potential impacts and assisting in development of qualitative vulnerability metrics for areas where applicable vulnerability models are not available. The methodology successfully considers network interdependencies and cascading failure through identification of hotspots and pinchpoints and the results present useful information to infrastructure providers and emergency managers.

The impacts included in this scenario may be overestimated due to the uncertainties in the vulnerability model and assumptions made in inferring LoS from the vulnerability metric. However, overestimating potential impacts fosters a precautionary approach to emergency management with the underlying philosophy to "plan and expect the worst, hope for the best". Despite its limitations the high-impact scenario is fit for purpose and it is anticipated that the scenario will stimulate thought and discussion around potential actions that could be taken to reduce these impacts.

6 Participatory Workshops To Engender Community-Led Action to Reduce Tsunami Impact and Increase Resilience

6.1 Introduction

The previous chapters in this thesis have contributed towards risk identification (Chapters 2, 3 & 4) and risk analysis (Chapter 5) within the wider Risk Management Framework and have involved communication and monitoring and review throughout the process (Sections XXX). This Chapter brings together the results of these previous chapters and proceeds to the next steps in the framework; evaluating risk and identifying risk treatment options with a greater component of communication and monitoring and review through participation of stakeholders in the processes involved.

This chapter seeks to address the following objectives (as listed in Section 1.5):

10. Share the methods and results of the investigation of historical tsunami impacts and inundation extents, as well as the inundation and impact (LoS) scenario development (Chapters 3, 4 and 5) with stakeholders and community representatives.
11. Collect and incorporate feedback from the stakeholders and community representatives on the past tsunami investigations and impact assessment.
12. Use participatory tools to:
    a. evaluate the consequences of the impact scenario on the community,
    b. explore community vulnerability and the capacity to respond to tsunami impacts presented, and
    c. co-develop a list of actions that could be taken by individuals, households and/or agencies to reduce tsunami impact both now, and during a tsunami warning.

Firstly, some context is provided around the purpose of conducting these workshops and reasons for the participatory methodology followed. The methods used to design the workshop and the workshop activities are then described. These are followed by the results, presented in the form of tables and lists which illustrate Chatham Islands community vulnerabilities and capacities as well as the actions which could be taken now, or during a tsunami warning, to reduce tsunami impact. Finally, a discussion of the methodology and results is presented with recommendations for future research. The results contained in this chapter provide useful information to the Chatham Island community including individuals, households, and agencies (including businesses, emergency management staff and volunteers) to inform future initiatives to reduce tsunami impact on the Chatham Islands. This chapter also contains useful lessons relevant to those working in community-based DRR and facilitating community workshops to reduce natural hazard impacts.

While the results of this chapter were based on the scenario developed in Chapters 3 and 4 (whereby disclaimer statements are provided regarding the use of the inundation and impact scenarios - Sections 3.1 and 4.1), the actions derived by the community reduce tsunami impact are generic and applicable for reducing tsunami impact for all tsunami scenarios.

6.2 METHODS

6.2.1 Workshop Context

As stated in Section 1.5, the aim of this thesis is to engender community-led action to reduce tsunami impact on the Chatham Islands by collating and co-developing information with the community and to inform future initiatives to reduce tsunami impacts. The physiological underpinnings of this community-based approach to DRR are based on the ideas that:

1. during a disaster, it is the community that is directly impacted and first to respond,
2. no one is more interested in reducing risks than the people who are likely to be impacted by a disaster,
3. nobody can understand local opportunities and challenges (including environmental, economic, social, cultural, institutional and political pressures that influence vulnerability) better than local people themselves (Gaillard & Mercer, 2013, p.98; Section 1.3.4.1). These local opportunities and challenges would not normally be understood by external researchers (Benson et al., 2007),
4. and locally-specific planning and action designed by stakeholders who have ownership of these plans to be carried out are more likely to carry them out than if they were excluded from the process (Healy et al., 2014; Mercer, Kelman, Lloyd, & Suchet-Pearson, 2008; Tompkins & Adger, 2004; Schoch-Spana, Franco, Nuzzo, & Usenza, 2007).

During this study (which follows the international standard Risk Management Framework) communication with stakeholders and participation of stakeholders/community members was sought at every possible opportunity within the tight timeframes involved. Chapter 3 investigated historical tsunami impacts and inundation extents on the Chatham Islands incorporating Tangata Whenua knowledge. For further risk identification and risk analysis (Sections 1.3.5.2.1 and 1.3.5.2.2) this information was then used to develop an inundation scenario (Chapter 4). The inundation scenario was used as the basis for assessing potential impacts on infrastructure and evaluating resultant LoS, which was informed by expert judgement by local infrastructure managers. A further step was required to share the results of the previous sections with stakeholders and to foster participation from stakeholders to evaluate risk (Section 1.3.5.2.3), monitor and review the results (Section 1.3.5.5.), and to inform risk treatment options (Section 1.3.5.3), all part of the communication process (Section 1.3.5.4).

6.2.2 Workshop Design

Hazard, vulnerability and capacity analysis (HVCA) involves participatory learning and action (PLA) and uses participatory tools, including those described in Appendix G.1, to understand exposure as well as community vulnerability and capacity (and the available resources) to resist natural hazards (IFRC, 2006; Cadag & Gaillard, 2012; Section 1.3.4.2). PLA aligns with the aim of this thesis, the physiological underpinnings listed above, and kaupapa Māori research methodologies (Māori-centered research for Māori, with Māori and by Māori, whereby Māori have conceptual, methodological and interpretive control - Smith, 1999; Section 2.1.2.4.1).

HVCA can inform and empower community-based disaster preparedness initiatives and allows local priorities for DRR action (IFRC, 2006; Benson et al., 2007). Activities and tools used to carry out HVCA are usually applied during community meetings or workshops (Chambers, 2002; IFRC, 2006; YCARE International, 2010; DRR Working Group; 2012) which are a suitable way to achieve the objectives of this chapter (Section 6.1). Workshop planning guidelines from Chambers, 2002; IFRC, 2006; DRR Working Group, 2012, as well as research supervisor Dr Kate Crowley's knowledge, skills and experience (she is highly experienced in facilitating HVCA workshops) were used to plan the workshops.

The workshop was framed around a set of questions, provided in the guidelines to help design workshops (DRR Working Group; 2012). These are listed below, accompanied by the answers specific to this study and which were used to design the workshop agenda and activities.

6.2.2.1 Why? What is the purpose of the workshop and what are the desired outputs?

As stated previously, the purpose of the workshops was to share the results of the previous sections and to foster participation from members of the community to evaluate risk (Section 1.3.5.2.3), monitor and review the results (Section 1.3.5.5), and to inform risk treatment options that are community-derived and will hopefully lead to community-led action (Section 1.3.4.1).

The desired outputs, produced by HVCA activities, include the Chatham Island community's vulnerabilities and capacities to respond to tsunami impact and actions that could be taken to reduce these impacts. Another, more important, desired outcome resulting from participation was that participants would find the workshop useful and informative so that they were empowered to take action to reduce tsunami impact following the workshop. We also hoped the participants would leave the workshop with better knowledge of tsunami hazard and risk facing the Chatham Islands and would be able to share this knowledge with their whānau, colleagues, managers etc.

Through providing opportunities during the workshop to discuss the information shared from the previous chapters, it was also hoped participants would review the results and amend them, or provide feedback which could improve the credibility of the scenario and reduce uncertainties in the study.

6.2.2.2 Who will facilitate and participate? Are there any existing political factors to be aware of and consider? How do the workshops fit in with surrounding DRR initiatives? Are there any expectations involved? How could these expectations be managed?

Communities are not homogeneous; differences and divisions exist due to culture, age, religion, gender and power or influence (Twigg, 2004). Existing power structures are important and often have heavy influence on the results of a VCA during community workshops (DRR working Group, DRR; IFRC, 2006; Twigg, 2004). The power and influence of individuals or groups within a community can be fuelled by: Mana (established respect), knowledge (e.g. experience and qualifications), resources or wealth, political titles (e.g. mayor, business managers), and social status/popularity (Mann, 1986; Bickerstaff & Walker, 2005). The voices of these individuals or groups often suppress others, meaning the voices of the less powerful/influential people who may represent the more vulnerable groups in the community are less likely to be heard. Thus, as Twigg (2004) explains, 'facilitators need to be careful, when choosing their local partners to organise and plan activities, and when identifying whom to include in those activities' (p.120).

The workshop was designed in collaboration with CIC and ECan to:

- Determine who would participate in the workshops.
- Manage power relationships in the room.
- Manage sensitivities around the potential expectations of agencies to implement actions from the workshop outputs.
- Ensure information was communicated in a way that was informative and didn't raise undue concerns.
- Ensure the workshops would fit in appropriately with surrounding initiatives.

CIC was concerned that there may be expectations following the workshop that the Council would carry out and lead the actions derived in the workshops. It was determined, through communication and collaboration with CIC and ECan, that the most appropriate way to manage sensitivities was to hold two separate participatory workshops; one with emergency operation centre (EOC) staff, and one with other key stakeholders including Iwi, infrastructure personnel, business owners, health providers and volunteers (the Chatham Islands does not have an established engineering lifelines group of CDEM staff and key infrastructure managers like most other CDEM Groups in New Zealand due to its small size). This was to ensure that EOC staff could openly discuss concerns, past learnings and introduce ideas without the possibility that expectations would form around suggested actions. A subset of questions was also added to distinguish whether the action could be carried out by individuals, households, agencies or require off-island assistance to spread responsibility of actions across all players. A disclaimer was stated at the beginning of the workshop to clarify that no agency or person would be held responsible for actions suggested by anyone. Splitting the workshops was also intended to encourage dialogue from all participants by reducing power differences in the room (DRR working Group, DRR; IFRC, 2006; Twigg, 2004).

Following advice from J. Paul, WREMO, (personal communication, August 2017), the word 'planning' was avoided in information sheets and invitations to the workshop. This was to minimise any expectation from participants that the workshop would result in the formation of a planning document with a designated agency to carry out this plan. Thus, the term 'action planning' commonly used in HVCA guidelines (DRR Working Group, 2012) was substituted with 'possible actions' within information sheets and invitations to the workshops.

The workshops, part of the wider thesis, fit into wider tsunami risk reduction initiatives that are currently in progress and that are planned (Section 2.1.4.2.6). The workshops provide the first understanding of community vulnerability, capacity and suggestions for future action which will help to inform future initiatives. Evacuation zones had been developed (and incorporated information from the investigation of historical tsunami impacts from Thomas, 2017 and Chapter 3 herein) and were due for release in November 2017. Therefore, in collaboration with Ecan and CIC, the EOC workshop also included introducing these zones, following the presentation on historical tsunami impacts. Three community meetings were also held (separate from the community workshop of this study) to introduce and collect feedback on these zones and to share the information collected in Chapter 3.

Kristie-Lee Thomas and Kate Crowley facilitated the workshop while Thomas Wilson, Helen Jack and Matthew Hughes provided technical support for questions within their expertise during the presentation and assisted in facilitating conversation during the workshop activities.

6.2.2.3 Where will the workshop be held? Is it a safe and culturally acceptable location for all participants?

The community hall (the den) was selected as a culturally acceptable, common ground to hold the workshop. The hall is commonly used by all for community events, meetings and celebrations. An offer was kindly made by Hokotehi Moriori Trust to use the Marae as the workshop venue. However, there may have been longer periods of time involved in partaking in the workshop if using a Marae, due to participants needing to be welcomed onto the marae (through a Pōwhiri) and may have been exclusive to participants who don't identify as Moriori (Section 3.3.2.1).

6.2.2.4 When and for how long? What time of month and time of day is best suited for community members to attend and be engaged? How long will the workshop go for?

Due to availability of key facilitators, Chatham Island emergency management priorities and the time involved in producing the data in Chapters 2, 3 and 4, the workshops were limited to be held around November. November is a busy time of the year on the Chatham Islands as the weather gets warmer and there are more jobs to do outdoors in preparation for Christmas and summer, schools hold their annual sport days and businesses are busy tying up ends before the end of the year. The community calendar, included in the Chatham Islands Community Focus newsletter, and the author's local knowledge of activities to avoid clashing with (such as social touch rugby on Friday evenings, when the boat with stores was due in, when the shop was open on the weekends, when the annual school sports days were etc.) were used to find a suitable date for the workshops. Weekends were ruled out due to activities and the community meeting planned for Thursday 17th of November 2017.

Workshops should ‘fit in’ with the daily routine of the participants/community (DRR Working Group, 2012). Sometimes participants are less engaged during the evening, or if the workshop is too long; in normal time, people are busy and often don’t have hours to spare out of their schedules (Twigg, 2004; DRR working Group, 2012). Activities included in HVCA guidelines usually take around 2 hours (YCare, 2010). Thus, the workshop was kept short (2 hours) to limit the time people had to take out of their day. The emergency manager kindly organised the EOC workshop and it was held in Council Chambers in the evening, after work, from 6 pm – 8 pm. The stakeholder workshop was held in the early afternoon, to prevent participants being less engaged, they could work in the morning and potentially take time off work to attend the workshop before school finishes at 3pm (assuming some of the participants may have children). The stakeholder workshop was organised by the facilitators; participants were invited by email and/or phone call and the workshop was held in a community hall in the afternoon (1pm-3pm). Invitations were emailed to company managers for them to pass on to their staff (as part of an ethical process as the workshop was during work hours) and included an information sheet on the workshop, participant anonymity and expectations (Section 6.2.2.2). This process was approved by the UC Human Ethics Committee.

6.2.2.5 What will the follow-up be?

It is important to follow up the results with the community after the end of the workshops/participatory activities. As the DRR Working Group (2012) indicate, the purpose of the facilitators is to record the information for the community, not to hoard the information. A NIWA Client Report, containing key results of the workshop has been drafted (as of April 2018) and has been sent to workshop participants for review before it is published. It is also hoped that there will be an opportunity to present the thesis findings to the wider community once it is completed, and that the relationship between UC, ECan, CIC and the community continues with future student projects to help to understand hazard risk on the Chatham Islands.

As part of good participatory practice and review, a survey was used at the end of the workshop as part of the follow-up process (Pavelin, Pundir & Cham, 2014; Israel et al 2010 and others). Surveys are a participatory tool used to collect data provided by the community (Twigg, 2004). The survey was developed utilising supervisor Kate Crowley’s experience to evaluate whether the workshop was useful, what information was most useful, whether the participants were likely to take action following the workshop and what could be improved in future workshops (Appendix G.2).

6.2.3 Workshop Activities and Agenda

Participatory workshop activities to carry out hazard/vulnerability/capacity analysis (HVCA) were reviewed from literature and NGO (non-government organisations) guidelines (Chambers, 2002; Twigg, 2004, IFRC, 2006; DRR Working Group, 2012; 1.2.4.2) and were informed by the above questions. Advice was also sought from experienced participatory workshop facilitators from NIWA and Wellington Regional Emergency Management Office (WREMO) to plan activities and the workshop agenda.

Based on the time available to run activities and the local context, it was assessed that brainstorming and timelines were the preferred activities (other options are provided in Appendix G.1). During brainstorming activities, the community can identify potential impacts, sources of vulnerability that generate these impacts, and identify capacities to reduce these impacts (DRR Working Group; 2012; Twigg 2004), thus it is a suitable method to carry out HVCA to evaluate risk, and identify risk treatment options. There are currently no procedures for evacuation controls on the Chatham Islands (O. Pickles, personal communication, August 3, 2017). Thus, another potential activity for the workshops included using timelines to evaluate priorities and coordinate action during a warning to reduce tsunami impact. The idea of timelines was adapted from the DRR Working Group (2012). Instead of an activity based around past events (information which was covered during interviews with Tangata Whenua), timelines could be used to plot and prioritise actions during a timeframe defined by the warning time expected for a regional or distant tsunami. Options for workshop agenda and activities to carry out HVCA were provided to CIC for feedback and input. The options included;

1. co-creating timelines to coordinate actions during tsunami warnings (of 12 hours or less) based on LoS expected following impact (evaluated in Chapter 5),

2. evaluating consequences of losing services (based on the impact scenario evaluated in Chapter 5) and prioritising actions and the resources required to restore function,

3. or a hybrid, where the consequences of losing services would be evaluated, before prioritising actions to reduce impact: before a warning (in normal time), during a warning and following impact.

Discussions with CIC, ECan and the research team identified the hybrid option as the preferred basis for the activities. This is because it facilitates a broad understanding of the potential consequences that losing services would have on the community, to allow a wider range of impact reduction initiatives to be derived that could be carried out now or during a tsunami warning by a range of players (individuals, households or agencies).

Subsequently the workshop agenda was formed (Figure 6.1). Both workshops followed the same design and were facilitated by the same people. The workshops were framed around an initial presentation which presented the known and expected tsunami hazard to the Chatham Islands and shared information collated during the investigation of historical tsunami impacts. An overview of modelled (Hikurangi and South America hydrodynamic animations) scenarios was provided and the presentation also covered past tsunami events that occurred in 1868, 1924, 1947 and 1960, the areas that were inundated and impacts that occurred – derived from Tangata Whenua knowledge. Following this, the inundation scenario (developed in Chapter 4) and the impact scenario (developed in Chapter 5) were presented to demonstrate the exposure of lifeline infrastructure on the Chatham Islands, and potential LoS – developed using the expertise of Chatham Island infrastructure managers (Chapter 5). These impacts were likened to those experienced in tsunami events around the world (including Samoa, 2009; GEJ, 2011 and Chile, 2015) through presenting photographs of impacted infrastructure to provide context and reasoning for the scenario results. The overview of tsunami impacts brought the scenario to life and was a primer for the activities that followed. Relatable information which can be personalised is useful for beginning dialogue in communities; especially if there is an obvious barrier between insiders/locals and outsiders/researchers (Cronin and Cashman, 2007). "This in turn can be used to provide the basis for beginning discussions about natural hazards preparedness, response and recovery." (King, 2007, p.70).

Large maps displaying the scenario were placed on the walls around the room and participants were encouraged to move around the room and interrogate the maps; workshop facilitators and other scientists were on hand to discuss the impacts with the participants (Figure 6.2). These maps provided a tool for discussion on where a tsunami may inundate, where critical infrastructure is located, how damaged infrastructure may be and as a result, how different areas around the island may be impacted in terms of loss of electricity, transport, communications, potable water and sewerage.

One of the objectives of the workshop was to collect community members' reviews of the process and outcomes of Chapters 2, 3 (investigation of historical events and hazard scenario development) and 4 (impact scenario development). Participants were invited to ask questions and discuss topics throughout the presentation. A discussion, including questions and feedback on the process and outcomes of

Chapters 2, 3 (development of hazard scenario) and 4 (development of the impact scenario) took place following the presentation and further opportunity to review results was provided when participants investigated the large scenario maps on the walls of the room. During the community meetings (separate to the workshops), Chapter 3's investigation was also shared, this provided a further opportunity to collect reviews from members of the community through discussions during and after the presentation. These amendments were recorded on the maps (by participants drawing additional assets on) and facilitators observed and took notes of any feedback during discussions.

A (voluntary and anonymous) survey was also distributed at the end of the workshop for participants to reflect and review the usefulness of the workshop and what could improve the workshop (Appendix G.2). Data from survey responses were collated in an Excel™ spreadsheet under categories based on the questions asked in the survey, and used to analyse the results.

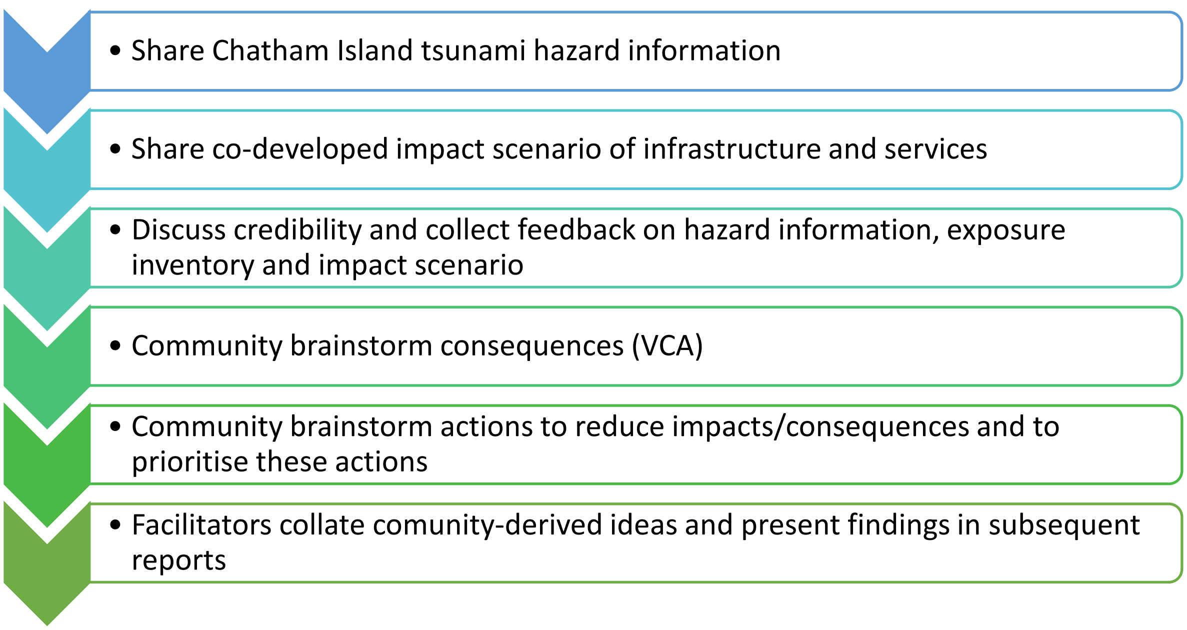

Figure 6.1. Workshop agenda

Figure 6.2. Introducing the impact scenario during the second workshop. Participants have been blurred to ensure anonymity. Source: Matthew Hughes, University of Canterbury.

We then facilitated a series of activities to instigate discussion on the potential consequences of a future tsunami on the community based on the scenario presented (Chambers, 2002). Participants in each workshop were grouped (3-4 people) randomly to catalyse deeper discussion and were provided with flip chart paper, markers and post-it notes. Participants were encouraged by facilitators to take the discussion in different directions and to focus on what they considered important; and were free to leave at any stage.

The activities were framed by the following guiding questions which were developed based on HCVA guidelines (DRR Working Group, 2012), and the hybrid option mentioned above:

1. Discuss the impacts and consequences of these loss of services
   - Consider the social, physical, economic and environmental impacts and consequences
2. Consider what actions can be taken to reduce those impacts if you had 12-hours warning
   - Consider the timeframes involved and resources you might need
     - Can you do this action as an individual, household, community, or would you need external assistance?
3. Consider what actions can be taken now, in normal time, to reduce those impacts

- Consider the timeframes involved and resources you might need
- Can you do this action as an individual, household, community, or would you need external assistance?

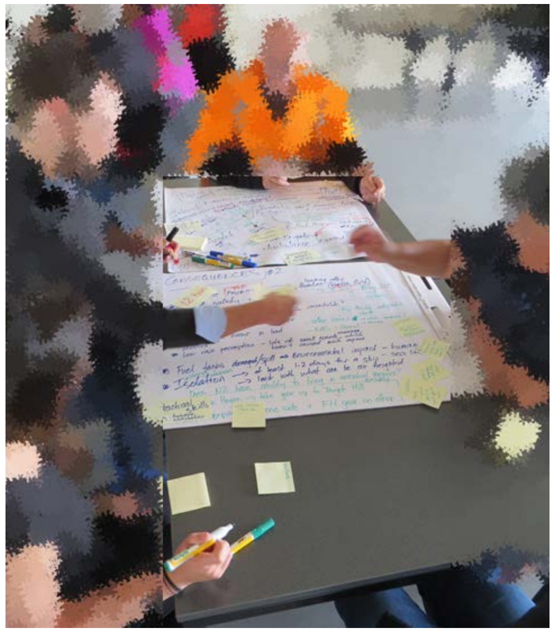

Figure 6.3. One of the workshop groups carrying out activity 1. Post-it notes were used by this group to distinguish which consequences could be reduced during warning vs which consequences could be reduced by taking action now, in the meantime. Participants have been blurred to ensure they remain anonymous Source: Kate Crowley, NIWA.

Data provided in form of flip chart brainstorms, post-it note priorities and additions to maps using whiteboard markers were photographed. The information was collated and transcribed for each group within each workshop under the three topic questions/activities carried out. The data were then analysed; key themes of consequences (resulting from LoS) were identified and used to inform the following results.

6.3 RESULTS

6.3.1 Participant Review of Chapters 2, 3 and 4

As part of objective 9 (Section 5.1), workshop participants and members of the community who attended the community meetings were invited to review the processes and outcomes of Chapters 2 and 3 (development of hazard scenario) and 4 (development of the impact scenario). The reviews included:

- Additional information on historical tsunami impacts, assets that were exposed at the time and confirmation of uncertain locations of assets and additional documented accounts which had been missed in the literature review.
- Review of the scenario extent, whereby local knowledge provided information on environmental factors not shown by the uncertain DEM. Participants noted certain river tributaries are susceptible to flooding and suggested the inundation extent should be extended around these areas. The scenario extent provided in Chapter 4 includes these amendments.
- Additional information on the exposure of assets. Participants drew missing water pipelines, pump stations and were incorporated into the revised scenario and exposure assessment (Section 6.3.1).

The reviews provided by members of the community were valuable for reducing uncertainties and making the scenario more realistic in the views of community members (important for the use of this scenario post-thesis in exercises). It was observed by the facilitators that, apart from these reviews, the inundation and impact scenarios were considered well justified by workshop participants and there was consensus that the inundation scenario and impacts were believable. This observation was justified by the way participants discussed the impacts, relating impacts the events that had occurred in the past and investment in the activity discussions around the fact action needed to be taken to reduce these impacts.

6.3.2 Impacts and Consequences of Reduced Levels of Service

Participants were asked to brainstorm initial consequences that may occur due to the loss of infrastructure services in the scenario and to focus on the most detrimental direct and indirect impacts (due to restrictions in time – we didn't have all day to discuss every possible impact). These were impacts that would cause a delay in response and recovery and/or cause significant loss of resources, affect people's livelihood or in the worst-case, life. Analysis of workshop outputs and observations revealed that participants identified four main interconnected themes of impact on: communications; livelihoods; isolation; and impacts on the natural environment.

6.3.2.1 Consequences of Reduced Communications:

Participants identified that communication services were important during tsunami warning and response. All workshop groups identified that external and internal communications during a tsunami event are crucial. Operational and adequate external communications with New Zealand are required to receive timely warning and information, and internal communications within the island are required to spread warnings and for the community to remain updated (Section 5.4.1.1.1, Appendix C).

It is important that internal landlines are operational during a warning for communication between the EOC, area coordinators and the wider community. Not all households have landlines, or may be cut off, but with enough time the area coordinator (Section 5.4.1.1.1) can contact community members via VHF radio or in person. Landline or VHF communications are also important for area coordinators to update the EOC of any missing persons and the numbers accounted for at welfare centres/gathering points.

Participants mentioned the limited number of phone lines available for external communications to New Zealand (15 at one time) via satellite (Section 5.4.1.1.1). These are often overloaded during a tsunami warning and response as media and concerned family/friends call in and emergency personnel call out for information requests. This may slow external communication with MCDEM and thus delay warnings.

If a tsunami damages the landline and cuts power to areas (inhibiting internet use, use of handheld phones and potentially landline if the repeater relies on grid-provided electricity) isolated communities may be cut off from communication. However, participants mentioned that contact could be made via VHF/fisherman's radio as most residents have VHF in their homes, or by physically driving if roads and bridges are usable.

Although there is strength in having a close and relatively small chain of communications, this does rely on key people to be available and able to support their community before, during and after an emergency. There was agreement that mana (respect) and trust for key communicators during a tsunami response is important. Participants raised concerns that those people could become overwhelmed and exhausted during a long response/recovery period.

6.3.2.2 Consequences of LoS on Interconnected Livelihoods

Participants noted that loss of bridges and roads may prevent evacuees from returning to their homes and may stop people traveling to work. Breaks in the transportation network may also limit distribution of resources across the islands. There is no resident helicopter on the island to transport people or resources, unless one is visiting to spray gorse. Roads may be able to be restored using on-island resources but bridges will take longer to repair/rebuild (Section 5.4.1.1.2.8). Participants also explained that losing functionality of the airport would have significant effects on people's livelihoods. All frozen fish product is transported by air, if they can't fly fish, fisherman and factory workers won't have work. If life-flights cannot operate there will be stress on the health care system, which has a limited number of staff.

Participants identified that the loss of electricity to pump fresh water may be a major issue for drinking, hygiene, sanitation and economic reasons. Loss of electricity was deemed important to the livelihoods of everyone. Some residents on the main grid have back-up generators or are on solar power. One of the factories operates on its own generated power supply, but is exposed to tsunami inundation.

Participants noted that fishing boats and other fishing equipment such as trailers and tractors, pots and moorings are valuable. The amount of warning time will determine whether fisherman take their boats straight out to sea (forfeiting other equipment) or whether they will have time to collect pots and bring boats ashore to high ground saving their trailers and tractors also. Participants noted that returning from sea may be problematic if moorings, trailers and tractors are damaged and this would have long term financial implications.

Participants noted that a significant number of workers on the Chatham Islands are weekly earners. During a destructive tsunami and long recovery weekly earners may be unable to earn a living. Financial implications of short or long-term loss of earning is made worse given the high costs of living on the islands (Appendix G.3) which is explored further in the next theme, Isolation.

Participants also discussed impacts on the tourism industry. The main hotel is located at sea-level in a high tsunami hazard area, and tourists would need to be evacuated to the welfare centre if there was limited capacity among other accommodation. If access to and from the islands is impaired, significant resources may be required to accommodate tourists.

6.3.2.3 Consequences of LoS in regard to Isolation

Due to LoS of transportation infrastructure and response priorities given to larger populations it is possible that during and following a large tsunami event the Chatham Islands will need to be self-sufficient for a considerable amount of time. Participants acknowledged that isolation from New Zealand for long periods of time may have impacts on fuel availability, medication for those reliant on it, and as previously mentioned fatigue of those in roles of responsibility. Fuel depletion would exacerbate reduced electricity service (induced by tsunami impact), would likely need to be rationed, inducing economic loss and slow response and recovery.

Participants also raised the issue of expensive repair costs and noted that insurance would be vital. Isolation means that many products required for rebuilding must be imported and are therefore expensive due to the cost of freight. "In addition to the costs associated with shipping in materials, professionals such as builders, plumbers and electricians must usually be flown in from the mainland at the owners' expense. Finance and insurance for new builds are also much more difficult to secure," (Leung-Wai & Borren, 2017). Therefore, the cost of repair for someone on the Chatham Islands is significantly higher than on mainland New Zealand (Appendix G.3, Table G.2). Participants raised concerns that some may not have insurance or that insurance may not cover this type of event. Participants stated loss of heavy machinery and equipment (if there was not enough warning to shift) would mean recovery would be slow.

On-island isolation is also an issue. Participants identified that some settlements may be cut off by damaged roads or bridges and therefore distributing supplies could be challenging.

> *"Even if the airport is still functioning how will we distribute resources to town?"*

Finally, and crucially, the circumstance of living on an isolated low-population island means that most children leave the island to board at secondary schools around New Zealand (popular locations include Christchurch, Oamaru and Napier). There are no secondary or higher education facilities on the islands, although correspondence is offered. The cost of boarding school is high, and results in families being split between the mainland New Zealand and the Chatham Islands. During a high-impact tsunami event, communications with the mainland New Zealand and travel to and from are likely to be impaired. Children and other family members may be unable to return home during the initial recovery. Participants noted that this would be extremely stressful for family members.

6.3.2.4 Impacts on the Natural environment

Chatham Islanders are accustomed to living off the land and sea and have done so for generations. As mentioned in Section 1.4, seafood and agriculture are now substantial sources of income. Participants discussed the possibility of contamination of natural resources following tsunami impact and how it may be detrimental to food supplies and livelihoods. They were particularly concerned that damaged fuel tanks may lead to the pollution of seafood production areas and prohibit mahinga kai (food gathering).

Participants were also concerned about the impacts of salt water inundation on grazing land and fresh water supplies.

6.3.3 Vulnerabilities & Capacities

Key capacities (strengths) and vulnerabilities (contribute to impacts and which may result in greater impacts or a slower response/recovery) emerged from participants' discussions about the consequences of tsunami impacts on infrastructure (Table 6.1).

There was acknowledgement that some level of complacency exists when it comes to tsunami warnings which could increase vulnerability to impact. Since the 1960 event (some 60 years ago) there has been no inundation from a tsunami on the Chatham Islands. Recent tsunami warnings for the Chatham Islands (with the exception of the 2016 Kaikōura warning) have been 'beach and marine' warnings (Appendix C). Frequent 'beach and marine' warnings and lack of recent events that have inundated or caused damage on land may have resulted in a perception that tsunami on the Chatham Islands will only be of this size, not bigger. Social media posts during the 2016 Kaikōura tsunami event included photos of people collecting shellfish as waters receded and people joking about going surfing, both posts receiving many "likes" (Facebook, 2016). This complacency concerned workshop participants, as ignoring tsunami warnings not only endangers the individual's life, but the lives of emergency responders tasked with saving them. Tsunami are not all equal, but like other hazards such as earthquakes, occur in a range of sizes. Small tsunami (which result in beach and marine warnings) occur more frequently than large, damaging tsunami which inundate land. Participants agreed that all warnings should be taken seriously.

The Chatham Islands are about 800 km from New Zealand. As participants mentioned, Chatham Islands isolation can be viewed as both a strength and a weakness. Generations of living in isolation has fostered the skills to be self-reliant, adaptive and resourceful, and generated substantial social capital (relationships with people). However, isolation can also be a vulnerability/weakness due to issues of delivering resources, time and cost.

Many participants noted that most of the community should be able to cope until external aid and resources arrived (when envisioning approximately one-month isolation from A-NZ without external aid) because they are used to being isolated, are experienced with losing electricity during power cuts and reliant on their own resources. There is an abundance of local protein sources on-Island (shellfish, crustaceans, wet fish/fin fish, sheep, cattle, wild pigs etc.), and many residents have vegetable gardens and buy other imported foods in bulk. Participants were confident food would not be a major issue. However, there was some concern relating to 'new islanders' and younger community members who had become reliant on services "and may not be able to cope". They may not have sufficient stores of food, water and fuel. There was also concern for other vulnerable members of the community who may be sick at the time of an event or who rely on medication. Questions were raised whether these people or the island would have sufficient supplies of medication. Other key capacities and vulnerabilities are summarised in Table 6.1.

Table 6.1. Summary of key capacities and vulnerabilities of the Chatham Islands community to respond to a tsunami warning and impact.

Key Capacities	Key Vulnerabilities
• Members of the community are self-reliant, adaptive, and resourceful. • High social capital (relationships, trust, sharing of resources, kaitiakitanga and manaakitanga). • Practiced evacuations and relocation of some key assets. • Good relationships with external resource providers. • Abundance of local sources of food. • Residents' bulk stores and some keep personal stocks of fuel. • Back up communication channels (e.g. VHF radio). • Some back-up generators.	• Isolation (providing resources and aid, time delays and high cost). • Reliance on NZ for distant tsunami warning. • Reliance on key personnel to support the community who may become exhausted due to lack of replacement staff. • Limited number of external phone lines. • Community complacency during tsunami warnings. • High repair costs (freight). • Economic dependence on transportation network, electricity and fuel. • People reliant on medication, as well as the elderly and young . • Boarding schoolers away from family during a disaster.

The purpose of the following exercises (questions two and three) was for participants to identify actions that would reduce these key vulnerabilities and to build capacities (DRR Working group, 2012).

6.3.4 Actions during a Warning

Once participants had identified the most problematic impacts they were then encouraged to discuss what actions they could take if they were to receive a 12-hour window of warning (the likely amount of warning received following an alert from MCDEM of a South American tsunami event – the most frequent source of tsunami for the Chatham Islands) (CCC, n.d; Power, 2013; Lane et al., 2016).

Participants within all groups believed that 12 hours' warning provided adequate time to;

- Coordinate the movement of the most vulnerable (children, sick and elderly) to places of safety e.g. hospital or evacuation zones/mustering points, and that this would be a priority.
- For people in evacuation zones, gather necessary belongings and supplies (food, water, clothing, camping gear/bedding, pet food/cages, and sentimental items) and move to higher ground.
- Relocate heavy machinery and emergency service vehicles to safe designated sites and to locate these in different areas (e.g. on either side of Waitangi Bridge), an initiative currently in place and which has been practised several times. Suggestion was made to also pre-position sat phones, back-up generators and water tankers across the island.
- Relocate factory product and store stock to fridges/freezers/storage located outside of evacuation zones.
- Collect holding pots and take fishing boats out to sea, or bring them ashore using trailers/tractors to relocate them to high ground.
- Remove 'loose' shipping containers, equipment, machinery and other valuable items from the wharf.
- Drain fuel from bulk storage facilities into mobile tankers, drain fuel sitting in pipelines and fill emergency response vehicles and equipment with excess fuel.
- Potentially evacuate tourists, via plane (1 hour 45 minute flight time), to relieve stress in recovery if tourists were to become stranded, having to rely on the community's resources. Planes could be left in New Zealand, ready to bring in resources for recovery (capability to land on rough tarmac/grass).

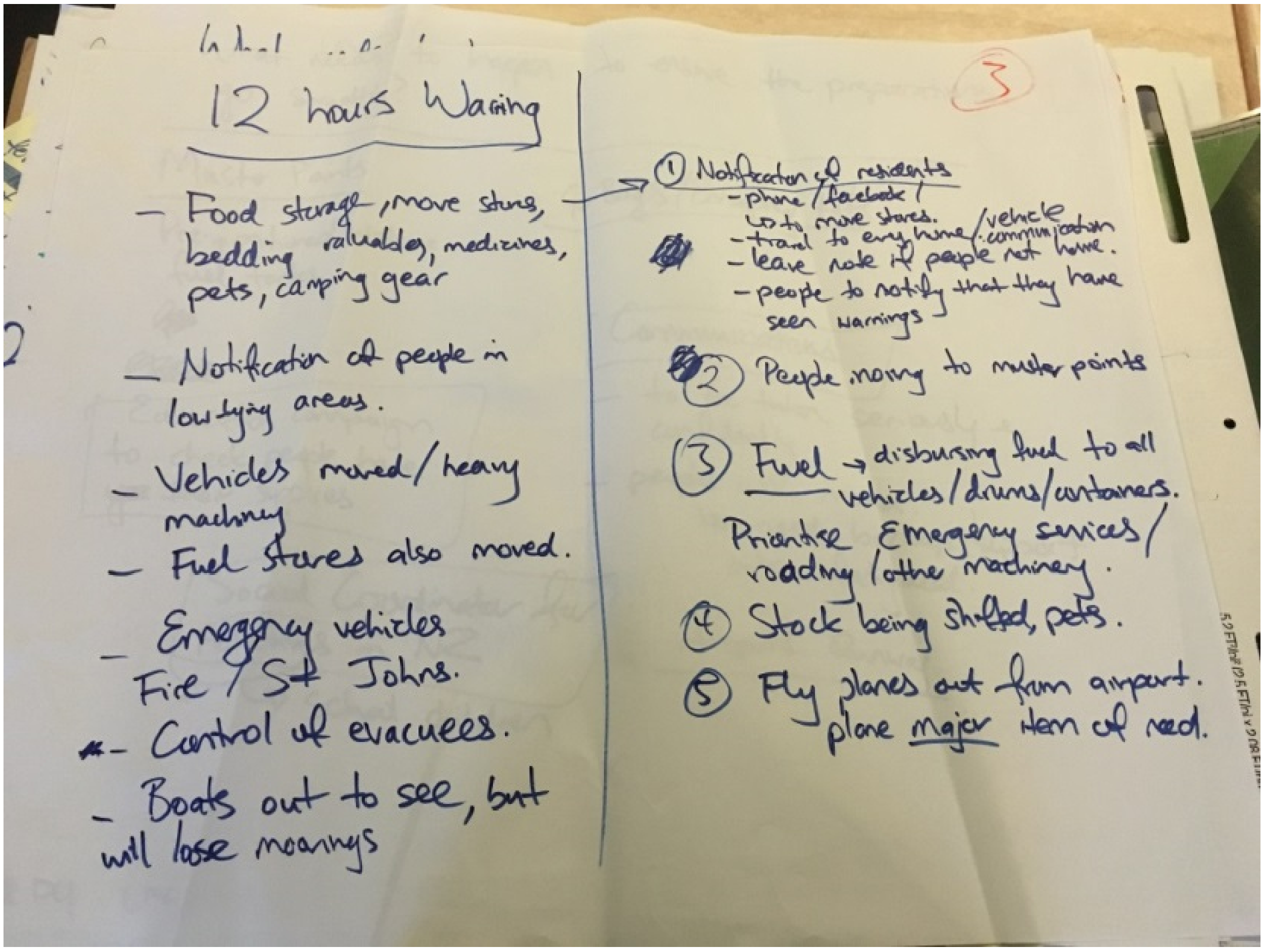

Figure 6.4. Actions that could be taken when given a 12 hour window of warning (left side of page), and prioritisation of these actions (right side of the page). Derived by a group at the stakeholder workshop.

These actions rely on key individuals being available, and understanding their role within the communication chain (see Section 5.4.1.1.1) as well as having good communications between New Zealand and the Chatham Islands for reasonable warning time and information updates.

6.3.5 Immediate Actions

The final exercise encouraged participants to consider, given their previous discussions, what they could do now to reduce risk and prepare for a tsunami.

Table 6.2 provides a breakdown of the key actions discussed. The discussions focused on ensuring that the community receive warning messages and then know what to do (who to coordinate with, what to bring and where to evacuate as necessary) as well as ensuring an up-to-date inventory or stock check of on-island resources is generated.

Table 6.2. Actions that could be taken now to prepare for a tsunami. Derived from all participants in both workshops.

People	**Resources**	**Communications**
All area coordinators can communicate across multiple channels (including access to satellite phones)	Set up a secondary power generator in Waitangi	Run exercises and drills especially for new emergency personnel, public and area coordinators.
All households know where safe areas are and that each household has a plan including for pets and for school children/family members on mainland New Zealand as well as a pre-packed go-bag	Assess capacity of welfare centres, their access to resources and how long they can be self-sufficient for (including without mains power, landline and mains water)	Have a process to regularly check all communication channels are functioning (e.g. testing VHF and sat phones regularly)
Households and businesses to store their own bulk fuel (this is starting to happen due to recent delays)	All organisations and businesses should have a plan prepared for evacuating staff and mobile/valuable equipment or assets as well as contingency plans for operation without mains electricity, water and landline.	Undertake a regular stocktake to check repeaters have sufficient power e.g. solar or backup generators and fuel for these.
Establish population census in crisis including the monitoring who is on and off island with passenger lists (possible issues around confidentiality), including visitors.	Generate an inventory of resources on island (emergency accommodation, people/skills, fuel, heavy moving equipment, vehicles available for evacuations etc.)	Undertake an education campaign to make sure everyone knows what the communication approach will be during an emergency so that telecommunications are not overloaded. This could include a single channel (such as a designated Facebook page) which can be used by the community to coordinate resources and actions during a warning and in response with information posted regularly to update family and friends.
Put in place plans to assign back-up/deputy area coordinators and emergency response personnel to provide over-worked people with rest.	Pre-position emergency kits (water, shelter, food, clothing, fuel) in safe zones and on isolated islands/areas. (Council moving to new site – opportunity to relocate bulk fuel	Families with children at boarding school have a plan for communication loss and support system (relatives who can retrieve children from boarding school)

6.3.6 Was the workshop Useful for Participants?

As mentioned above, a survey was distributed at the end of the workshop to ask participants whether they thought the workshop was useful, what parts were most interesting or useful, whether the participants were likely to take action to reduce tsunami impact after attending the workshop and what parts of the workshop could be improved (Appendix G.3). The survey was anonymous and entirely voluntary. Data from the returned surveys were analysed and the following results were found;

- All respondents found the workshop useful.
- All respondents found information on tsunami hazard (sources, travel times, wave heights, and likelihood) useful.
- All respondents found information on how infrastructure may be impacted as well as what that would mean for provision of essential services useful.
- Most respondents found the activities useful and respondents commented that the large scenario maps and visualising how different areas may be impacted were useful. Respondents also found the activities useful to reflect on 'how prepared we are as individuals'.
- The survey respondents did not find the information surprising but found the historical information interesting (the number of events, what areas were affected). Respondents also expressed interest in the difference in response depending on warning time, as well as discussing different communication strategies.
- Four out of six survey respondents said they would definitely take action to reduce tsunami impact, the other two said they would quite likely take action. Two of the 'definitely take action' respondents were responsible for emergency management as a part of their occupation. Other reasons were letting family and staff know about the risk (informed and aware) and because one participant's house was at particular risk.
- Suggestions included having the workshop in the evening so that they didn't have to leave promptly/early or had to arrange cover. Another suggestion was to ask people if they were aware of the information presented and to enforce the idea of spreading this information to keep family and friends informed and safer. Other comments included that they thought the workshops went well and the information was well delivered.

On reflection, adding a question asking, 'what action people might take following the workshop' would add value to the survey. This would provide an indication of the kinds of action the workshop engendered, useful for developing methodology for future workshops.

6.3.7 Contrasts between the Stakeholder and EOC Workshop

There were both similarities and differences in the results produced by the groups of the stakeholder workshop and the EOC workshop.

Similarities included:

- Both workshops acknowledged the Chatham Islands may be isolated from external assistance but elaborated on the capacity of Chatham Island community to pull through together, built on a foundation of high social capital (strong, intergenerational family ties) and a shared value of manaakitanga. Both workshops explained that people of the Chatham Islands are resourceful, adaptive and would share resources to restore function, worrying about cost later.
- Both workshops prioritised notifying everyone of a tsunami warning, evacuating, relocating vulnerable people and strategically relocating key resources (fuel, vehicles, boats, water) during a tsunami warning.
- Both workshops highlighted the importance of communication, transportation and energy infrastructure and identified similar actions that could be taken to reduce loss of service during tsunami warnings and post-impact.
- Both groups identified an updated inventory of on-island resources needed to be conducted, now, before a tsunami occurs.

Differences included:

- Stakeholder workshop participants mostly described consequences that loss of services would have on livelihoods; including getting to work, loss of income, being isolated from school children, friends and whānau in New Zealand and high repair and recovery costs. By contrast the EOC workshop identified consequences relating more to response and recovery operations such as rationing of fuel and water supplies and stress on the health care system if life flights couldn't operate.
- Stakeholder workshop participants also identified issues concerning community welfare, such as the lack of a community hub or meeting place for South Coast and Waitangi residents on the East side of the Waitangi Bridge (there used to be a community hall, this is now decommissioned). Kopinga Marae is the designated evacuation centre for the general area. However, if Waitangi Bridge is unusable following tsunami impact, there is no 'mustering' facility west of the bridge. Stakeholders also identified the worst time for a tsunami warning/impact

would be during a large occasion (weddings, birthdays, New Year's Eve, tangi) where people have been drinking; as well as during the summer when people go camping and are harder to contact or if the weather was bad, exacerbating impacts. This should be considered in future training exercises. The EOC workshop considered issues concerning response operations such as high turnover of emergency staff (police, doctors, nurses, infrastructure managers, and MAF officers), shelf life of Avgas and petrol and transport links between isolated areas including remote islands with conservation volunteers/workers.

- The Stakeholder workshop participants commented on the sense of complacency by some of the community regarding tsunami warnings. By contrast EOC participants commented on the highly cooperative manner of the community to evacuate during a warning.
- There was variation in the actions produced by each workshop that could be taken now, or during a tsunami warning to reduce impact. The EOC participants focused on operational actions during warnings such as coordinating the relocation of people and assets. The Stakeholder workshop participants thought more outside the box including strategically relocating assets the EOC didn't discuss including generators, sat phones, frozen fish product, movable chillers, food stores, and identified useful items that could be taken when evacuating such as camping gear to relieve stress on welfare centre resources. The EOC focused on opportunities for relocation of vulnerable assets and building capacity of residents through having go-bags and storing household fuel stocks. The stakeholder workshop participants also discussed education campaigns, pre-positioning water and fuel at mustering points, and plans for relieving staff and external communication including with boarding schools. They also suggested evaluating the current capacity of evacuation centre and resources that may be needed.

6.4 Discussion

6.4.1 Discussion of Methodology

The workshop design, including the presentation at the beginning of the workshop and the three activities, enabled the participants to reflect on their own individual, household or agency tsunami preparedness and personalise the problem. The workshop style was designed so that participants could share their concerns and ideas with each other, therefore encouraging collaborative planning.

There were some clear successes from this approach:

- Introducing the tsunami hazard via historical records of past events was well received and immediately engaged the participants. Providing close-to-home examples and sharing Chatham Island history was a critical step to personalising the tsunami threat and encouraging ownership of the problem (Cronin & Cashman, 2007; King, 2007).

- The workshop materials included large ‘scenario’ inundation maps for each key region on the islands. This visualisation of potential inundation and areas affected by loss of services acted as a useful talking point, again illustrating the hazard and making it personal to the community. These maps also provided opportunity to ground-check the scenario and gather feedback on different ways the infrastructure system may react based on local knowledge.

- Engaging a group, rather than interviewing one on one, ensures a sharing of ideas and ownership of the actions that come out of the process. This crucially identified some elements that had not been considered, such as but not limited to:

    - Having family plans for those with children at boarding school on mainland New Zealand.
    - Pre-positioning resources/survivor packs in isolated locations, especially inhabited islands offshore.
    - During a warning, strategically placing water tankers, satellite phones, radios and fuel.
    - The lack of a designated community hub for residents located on the west side of Waitangi Bridge.
    - Consideration of moving all fishing equipment inland if time allowed.

6.4.2 Discussion of Results

Overwhelmingly, participants discussed the impact reduced or loss of services would have on their livelihoods, as well as the ability to survive in isolation for a potentially extended period post-tsunami without help from mainland New Zealand. The workshops highlighted the important interconnected nature of livelihoods and key infrastructure. Examples include the reliance of the fishing industry on fuel, transportation on-island and off-island via aircraft, and operation of fish factories. Considering the high cost of importing materials required for repair and rebuild, ensuring that those reliant on the fishing industry are able to earn a living will have a significant influence on length of recovery.

6.4.2.1 Contrast Between the two Workshops

Facilitating two workshops with different participants was an important consideration when co-designing the workshop programme and structure with researchers and key project collaborators who oversee emergency management for the Chatham Islands. The workshops were facilitated the same way by the same facilitators and followed the same design to allow comparisons to be made. The contrasts between the workshops are outlined in Section 6.3.7 and revealed useful information for EOC/CDEM Groups; from a research and policy point of view, the contrast highlighted where successes have occurred and where on-going challenges and gaps are. Similarities between the workshops demonstrate that most people on the Chatham Islands share the same priority: to look after their people and their community foremost. Strategically relocating resources was also a priority; an action already practiced by the EOC. There was also a shared vision for an on-island resource inventory, which is something EOC plan to carry out. Both workshops also acknowledged potential isolation from external assistance and the importance of infrastructure services during that time of isolation, highlighting the importance of the actions derived by the participants (listed in Sections XXXX & XXX).

Differences highlighted some gaps and areas for future work. These differences could be attributed to the role of EOC staff to coordinate response and recovery operations as their contributions concentrated around likely consequences and actions involved around operations. Facilitators observed a sense from the EOC workshop that tsunami-related operations are well practiced and much planning had occurred already. The stakeholder workshop detailed likely consequences to community livelihood and identified a range of actions that could be potentially very effective in improving tsunami readiness, response and recovery. The participants of the stakeholder workshop identified that:

- Community education campaigns (that are more engaging than website and pamphlet information) would be useful to help reduce complacency, and coordinate critical resources and everyone during a warning, this could include a community tsunami hikoi (community event to walk/practice evacuation routes) (East Coast Lab, n.d).
- Some members of the community would like to be more involved in emergency management planning and processes. These members sought for greater transparency around how tsunami warnings work, how decisions are made and what plans are underway and planned, which in turn would increase trust and enhance mana (Appendix A) of those coordinating response during emergencies.

- There is a need for a plan to relieve EOC staff, emergency volunteers and key company managers (including of infrastructure organisations) responsible in response and recovery operations.
- Communication plans are also required around communication between parents, boarding school students as well as other whānau who may be separated (between Chatham Islands and New Zealand or elsewhere) during a high-impact tsunami event to prevent overloading of external phone lines and to reduce stress.
- There is also a need to evaluate the capacity of designated welfare centers; how many people they can provide for? What requirements will these people have (young, elderly, tourists)? How long would resources last? This would provide useful information for CDEM and the community who could assist in providing resources.

Involvement of wider members of the community during the stakeholder workshop allowed deeper discussion of consequences on people's livelihoods and 'outside of the box' actions that could be taken by the community to reduce potential impacts, assist with EOC operations and relieve stress on EOC staff and emergency volunteers. These were a key success of the participatory approach of these workshops.

6.4.2.2 Other observations

Other observations were made during the workshop. The participants focused on key requirements for the functioning of the community, rather than the functioning of their household, family group or individually. There was an in-built acknowledgement that in a small island community each household and individual relies on a functioning and pulling-together of the wider community in order to respond and recover. Acknowledging that the community requires an ability to survive and start recovering independently is distinctive to isolated communities (Cox & Hamlen, 2015). Ironically, a key concern was the reliance on New Zealand for receiving the initial warning. A distant-source tsunami may not have any natural warnings on the Chatham Islands (e.g. shaking would probably not be felt on the islands in advance). Therefore, although the community has capacity to survive and be self-reliant until external aid, there is total reliance on contact from New Zealand to provide warning.

6.4.3 Limitations

6.4.3.1 Number of workshop Participants and Representation of the Community

Stakeholders attended both workshops voluntarily and represented a range of sectors across the islands including fisheries, agricultural, welfare, emergency management, emergency volunteers, health services, conservation, and infrastructure. The participants who attended provided a good representation of these sectors in community. However, more participants from a wider range of industries/community groups would have provided a wider view from different perspectives and may have provided more consequences and potential actions to reduce tsunami impact. It is noted that Iwi trust members, hospital staff, fish factory managers and some infrastructure company members who were invited could not attend. The workshops were limited by the targeted representatives invited, including EOC staff and community/industry representatives.

It was requested by a key, local project collaborator that two workshops be held; one focused on EOC and Council perspectives and the other focused on other key stakeholder/company managers' perspectives due to concerns about expectations of actions being carried out (Section 6.2.2.1). Being respectful to community representatives' and stakeholders' requests is a requirement of working with and for communities and is simply part of the process (DRR Working Group, 2012). Although, ideally, we would have liked to openly invite all members of the Chatham Island community, stakeholders provided useful results. Other community groups that were not represented in these workshops included education representatives, hospitality and accommodation, young adults and children.

The workshops were held in November 2017; November is generally a busy month on the Chatham Islands (Section 6.2.2.4). This was predicted, but unavoidable due to timelines involved in the scenario development, availability of facilitators and EOC staff. A number of invited participants could not attend due to other commitments. This may have limited the results, which therefore may not be representative of community groups that were not included in the workshop progress.

The stakeholder workshop was held from 1-3 pm and the EOC workshop was held from 6-8 pm. The later workshop was a little rushed, and shorter than the afternoon workshop as we didn't want to keep participants late in the evening. This workshop was less productive and participants were more inclined to leave early. On the other hand, participants needed to take time off work to attend the stakeholder workshop.

Only a 50% of the participants returned the surveys, and ethical requirements prevented facilitators from following up with participants to return surveys as the survey was a voluntary process. Therefore, the results contained in Section 6.3 are only representative of half the participants and may not represent the views of everyone.

6.4.3.2 Power Relationships

There were powerful individual participants (of authority and mana) with powerful personalities in both workshops. They had the loudest voice in the room or in their group and their words carried significant weight. Overshadowing of other participants was observed and this may have limited the variety of opinions included in the data. Facilitators (who are all experienced teaching staff or training/workshop facilitators) tried to monitor this situation and provide opportunities for those who were being over-spoken. As Twigg (2005, p.123) states “Local authorities, political leaders and business people are often keen to be involved, but may have little understanding of the needs and circumstances of the most marginal and vulnerable groups; or they may have their own agendas. On the other hand, members of local élites cannot be disregarded as they have the power to disrupt community-based initiatives. Deciding how to acknowledge and include local leaders is one of the most difficult challenges in participation”.

The power relationship between the facilitators and the participants is also acknowledged. This power relationship was not observed to have effects on the process and outcomes of the workshop. Participants were actively engaged, far from shy, mostly carried their own conversations and bounced ideas off one another; facilitators only guided conversations if participants were straying from the topic, to investigate issues deeper or to move forward to complete the activities in the timeframe allowed. The lack of power differences could be due to one of the facilitators being a local, and familiarity of some of the other facilitators (through involvement in earlier stages of the project). As Chambers (1994) notes, local facilitators obtain contextual knowledge of the topics being discussed, and are, ultimately, familiar faces. The lack of power difference could also be possibly attributed to age differences; the facilitators being younger than most workshop participants. In Māori views, people who are older than you have more knowledge, experience and power and should be respected; the participants may have assumed this role. Another observation was that whilst a serious topic was being discussed, shared senses of appropriate humour (e.g. referring to tourists, including the facilitators, as ‘loopies’ as the locals call them) between the facilitators and participants allowed conversations to flow more naturally, casually and comfortably.

6.4.3.3 Recommendations and Future Work

Some key learnings were reflected upon following the co-designing, recruiting participants and facilitating the workshops:

- The presentation really set the scene for the workshop and locally specific context gained the participants engagement.
- It is agreed by the workshop facilitators that holding separate workshops for EOC and the community provided useful outcomes and reduced the influence of power relationships in the results. Co-designing the workshop with key local project collaborators (ECAN and CIC) and respecting their opinions led to this process.
- Although it takes time, we would recommend ringing participants on the day and reminding them of the workshop/activity, especially in rural communities where people may not check or respond to emails regularly.
- We would recommend setting time aside at the end of the workshop for participants to fill out the surveys to increase the chances of receiving surveys back.
- A project timeframe longer than 12-months, and/or more planning may allow more flexibility in suitable workshop times that better suit the participants.
- The evening workshop did involve less engagement and although participants in the afternoon workshop needed to take time of work, more engagement was observed and a greater number of 'outside-the-box' ideas were brainstormed.

The workshops have further developed and/or strengthened relationships/interconnected people in the public and within the research/practitioner community. The workshops are therefore able to support ongoing work or new initiatives on the Chatham Islands to reduce natural hazard impacts. Future work could include:

- Open invitation workshops, following the same process (but incorporating the lessons presented in this Chapter) and at a range of times (weekend, evening and week day) to include perspectives from a wider range of community groups (e.g. education (teachers and children), tourism and young adults).
- Follow-up workshops to help facilitate community-led action to carry out the initiatives suggested in this Chapter.

6.5 SUMMARY

This chapter evaluated the potential impacts of a future tsunami on the Chatham Islands and aimed to engender community-led action to reduce tsunami impact by facilitating a participatory workshop with the Chatham Islands community, which fostered local knowledge-informed shared action planning. During two workshop sessions, information from the previous chapters in this thesis was shared with participants representing a range of sectors of Chatham Island society, to review and discuss the methods used and outputs; addressing objectives 8 and 9. Through participatory tools, participants then discussed what the worst impacts maybe and what could be done to reduce these impacts (Objective 10a) which allowed the participants to identify key vulnerabilities and capacities within their community (Objective b). Objective 10c was then addressed through activities 2 & 3 to co-develop actions to reduce tsunami impact on the Chatham Islands.

The workshops enabled the participants to personalise the problem, share concerns and ideas therefore encouraging collaborative planning. Overwhelmingly participants discussed the potential impact that loss of essential services would have on their livelihoods. Chatham Islanders have great capacity to survive on their own if disconnected from services from the mainland for limited periods. This is due to generations of living in isolation, encouraging individuals to be highly adaptive and resourceful. However, participants also identified key vulnerabilities in dependence on lifeline infrastructure and essential services during warnings, response and recovery. The workshops highlighted the important interconnected nature of livelihoods on the islands and key infrastructure; if the Chatham Islands are isolated from external resources, the performance of essential services and on-island capacity to restore services will have considerable influence on response and recovery. Discussions raised issues that had not been previously considered and cultivated ideas to mitigate impacts and identify actions that individuals, households, the community or agencies could carry out to reduce tsunami risk. The community-derived actions to reduce tsunami impacts contained in this chapter are useful to the Chatham Island community, infrastructure companies, business owners and emergency management agencies.

7 CONCLUSIONS & RECOMMENDATIONS

7.1 CONCLUSIONS

The aim of this thesis was to engender community-led action to reduce future tsunami impact on the Chatham Islands by collating and co-developing information with, for and by the community (which includes individuals, households, businesses and agencies responsible for emergency management on the Chatham Islands) to inform future initiatives that are useful and usable (as stated in Section 1.4). This involved combining scientific and local knowledge during all phases of the risk management process. To inform DRR initiatives (risk treatment options), further information was required to better understand tsunami hazard for the Chatham Islands (Chapters 3 and 4). As available tsunami footprints were limited and uncertain, Chapter 3's information was used and combined with tsunami models to develop an inundation scenario to provide a hazard footprint for an impact assessment (Chapter 4). An assessment of tsunami impact on infrastructure was then carried out to evaluate potential levels of service following a high-impact tsunami event (Chapter 5). The impact scenario was then used in the participatory workshops to derive potential actions to reduce these impacts (Chapter 6). The main conclusions of these investigations are outlined below.

7.1.1 Improving Current Understanding of Tsunami Hazard for the Chatham Islands (Chapters 3 & 4)

A unique approach was taken to improve the current understanding of tsunami hazard of the Chatham Islands through combining a comprehensive investigation of documented accounts with Tangata Whenua knowledge to evaluate the impacts and inundation extents of past tsunami events. The methods used were effective and a wealth of important information was brought to light. Of most significance, were the number of fatalities that occurred in the 1868 event and the revised date of the 1924 event, as well as the derived inundation extents. These inundation extents provide important information on what areas are susceptible to future inundation and where tsunami inundation can occur around the Nairn River in Waitangi (Figure), an area not inundated in hydrodynamic model runs.

The derived inundation extents showcase the importance of historical event information in providing additional information to improve or justify uncertain scientific models. Chapter 4 showed how uncertain models could be combined to incorporate areas of inundation well justified by empirical impacts, as well as models which consider changes in topography since those events resulting in different areas being susceptible (or less susceptible) to future tsunami inundation. Chapter 4 also demonstrated how Tangata Whenua knowledge can be incorporated into hazard research, especially in locations where tsunami hazard is not well quantified by scientific models. Tangata Whenua knowledge formed a key component in developing the inundation scenario and its incorporation fostered invested belief in the scenario by community members who participated in the workshops.

7.1.2 Assessing Tsunami Impacts on Societal Assets (Chapter 5)

This Chapter presents the most comprehensive infrastructure exposure inventory available for the Chatham Islands and will provide useful data for infrastructure providers, emergency management and future research projects. These data can be made obtainable upon request to the author. Section 5.4.1.1 provides a useful summary and compilation of infrastructure network interdependencies and key vulnerabilities to tsunami impact based on expert opinion provided by local infrastructure managers.

The methodology used in this chapter to evaluate impacts was adapted from standard practice based on availability of data vulnerability models for this area. This study demonstrates the value of expert judgement in determining potential impacts and assisting in development of qualitative vulnerability metrics for areas where applicable vulnerability models are not available. The methodology successfully considers network interdependencies and cascading failure through identification of hotspots and pinchpoints and the results present useful information to infrastructure providers and emergency managers.

Despite limitations, a justified, high-impact (but not far-fetched) scenario was generated utilising expert judgment provided by infrastructure managers. The impact scenario was reviewed by participants in the workshops and their engagement and investment in the impacts assured the scenario was well justified and possible.

7.1.3 Community-Derived Actions to Reduce Tsunami Impact (Chapter 6)

Drawing from ‘participatory learning and action’ (PLA) and ‘hazard vulnerability capacity analysis’ (HVCA) methods, a facilitated workshop was designed to encourage knowledge sharing, participation and action planning by members of the Chatham Island community. The workshop proved useful to both researchers and participants alike. Participants provided a valuable review of the methods and results contained in Chapters 3, 4 and 5 and reduced uncertainties in the modelling. During activities, participants identified key vulnerabilities and capacities and derived an extremely useful list of actions that could be carried out by individuals or groups in the community to reduce tsunami impact.

Although there was a high degree of confidence that the community could cope, the workshops highlighted some issues that the community had not yet considered but would be crucial during a time of high stress. With local planning and action these issues could be reduced and help to reduce tsunami impacts on the Chatham Island community.

7.1.4 Reflective Summary of Limitations

The results of this thesis were constrained by the availability of data and scientific tsunami information available for the Chatham Islands. Prior to this work, available data included:

- Compilations of some historical tsunami impacts and indications for the use of local and Tangata Whenua knowledge of tsunami.
- Useful, but limited or incomplete, inundation models.
- Minimal digital infrastructure data, and.
- A lack of vulnerability models applicable to all infrastructure types on the Chatham Islands, the best available qualitative vulnerability metric was used.

Local knowledge (provided by Tangata Whenua on past tsunami impacts and inundation extents, local infrastructure personnel in the impact scenario development and by workshop participants) was extremely useful for reducing some of these limitations. The inundation and impact scenarios were adequate for the uses involved in this study to evaluate possible impacts and co-develop actions to reduce these impacts. However, the inundation scenario and impact scenario could be greatly improved with more accurate model inputs and more participation by the wider community. In summary we made the most of scientific and local resources to better understand disaster risk and enhancing disaster preparedness.

7.1.5 Summary

Given their geographical location, the Chatham Islands are one of the communities most exposed to tsunami in New Zealand. The Chatham Islands have been impacted by several destructive historic tsunami. Increased coastal development, dependence on key infrastructure assets for livelihoods and community complacency has increased risk on the Chatham Islands. Therefore, a future tsunami event that inundates land has the potential to cause significant impacts on the people of this community, their livelihoods and key infrastructure. However, strong social capital and a self-reliant approach to daily life means the community has high capacity to prepare and reduce tsunami risk to improve efficiency of tsunami warning response and be in a better position to reduce and respond to tsunami impacts and to recover from a large event. As the workshop participants in this research noted, there is much that can be done to reduce tsunami impact and with the community's current capacities, these initiatives are achievable (if individuals, households, the community and agencies take ownership of these actions to carry them out). We hope the outputs of the workshops and this report inform and engender community led-action to reduce tsunami impact.

Overall, this research has demonstrated that working in close collaboration with the community and participation by the community in impact assessment processes can provide pathways for the improvement of scientific understandings of hazard, tsunami impacts as well as ensuring that information and assistance is available to communities to carry out their own action planning.

7.2 RECOMMENDATIONS AND FUTURE WORK

7.2.1 Recommendations

Operational:

- Reduce key vulnerabilities outlined in Table 6.1 (before a high-impact tsunami occurs) through planning with participation of the community to:
    - Derive a communication plan for whānau located across Chatham Islands and New Zealand (and afar) to prevent overloading of external phone lines (essential during a warning for updates from MCDEM).
    - Derive a plan to relieve exhausted emergency personnel during extended response and recovery operations.
    - Organise and implement an education campaign so that the community (individuals, households, businesses) understand tsunami hazard, potential impacts of a future high-impact event and know how to be prepared, including knowledge of the appropriate actions (such as those outlined in Section 6.3.4 and Table 6.2) to take during a warning. This could include exercises and drills (Table 6.2).
    - Generate an-on island inventory of back-up resources, their locations and key personnel required to operate resources. As well as assess the current capacity of evacuation centers (Table 6.2).
    - Pre-position emergency kits (water, shelter, food, clothing, fuel) in locations that may be isolated during a high-impact event, such as in Kaingaroa and on offshore islands (Table 6.2).

- Plan for future relocation of bulk fuel facilities, fire station, ambulance bay and transportation resources (road works machinery) permanently to a site/sites outside of tsunami evacuation zones.
- Generate a plan to coordinate impact-reduction activities during a tsunami warning. This could include: procedures for notifying and providing advice to fisherman (as to whether they should take their boats and gear out to sea or to come inland), procedures for closing bridges and ports after a designated timeframe to ensure safety of personnel relocating assets and activities of infrastructure companies to relocate infrastructure, turn sections of the networks off (e.g. isolating electricity lines in low-lying areas to prevent shortages or further damage), and drain fuel tanks etc. The plan could accommodate for different warning times and the actions achievable in each timeframe, e.g.:
  - A warning from South America (12 hours or less).
  - A warning from other distant sources (> 3 hours).
  - Minimal warning from a regional source (< 3 hours, < 1.5 hours for Hikurangi).
  - Or no warning from a local source (< 1 hour).

Research Methodology:

- Due to the time constraints of a 12-month MSc thesis, only one participatory workshop could be held (Chapter 6). For future participatory risk assessments, it is recommended another participatory workshop is added during the impact assessment process to create a community-derived impact scenario (instead of an impact scenario informed by interviews with infrastructure personnel). Although the impact scenario generated in this study was credible, participation of more infrastructure personnel, and discussions between personnel (collaboration of ideas) may derive a better understanding of exposure, infrastructure interactions, vulnerability and capacity to better evaluate potential impacts.
- This research was carried out by a local community member who had: knowledge of the community's history, cultural context, relationships with people and a personal connection to the Island. Pre-established relationships and trust was an advantage in carrying out initial engagement to establish context, as well as in advertising and recruiting participants for both interviews and the participatory workshops. Local knowledge of history and physical geography

was also useful during interviews with Tangata Whenua (Section 3.5.1). Involvement of local researchers in risk assessments for small, rural communities is highly recommended.

- This research followed the standard Risk Management Framework (AS/NZS, 2009) incorporating communication with, and participation of, the community in the risk assessment process as much as possible (in a 12-month timeframe). This thesis (and the methodologies included) provides a demonstrable application of how community participation can be successfully incorporated into the disaster risk assessment process, especially in the New Zealand context. This work can be used to guide similar future studies to develop useful and usable outcomes for, with and by communities. It is recommended future risk assessments follow a participatory approach, based on the learnings from this thesis and other participatory risk assessments, which encourages and guides stakeholder participation throughout the whole risk assessment process, from establishing context to implementing risk treatment options and in further monitoring and review processes.

7.2.2 Future Work

7.2.2.1 Future Work to better understand Chatham Islands Tsunami Hazard

- Seismic and bathymetric surveys are available for offshore and around the Chatham Rise. Future work could investigate local sources for tsunami generated by sub-marine landslides and active faults.
- Tangata Whenua knowledge and documented accounts have identified numerous sites that were inundated during past tsunami events. Further palaeo-tsunami investigations could investigate these sites for sedimentological traces of tsunami.
- Tangata Whenua knowledge and documented accounts provided minimal information for Pitt Island. Future work could involve investigating whether palaeo-tsunami deposits exist on Pitt Island to better understand tsunami hazard.

7.2.2.2 Future Work for Chatham Island Infrastructure Tsunami Risk

- The exposure inventory developed in this thesis could be improved with contributions from Chatham Islands infrastructure providers to include assets such as all fuel tanks (including personal supplies, petrol and gas), fuse boxes, water tanks, power insulators and wires specific for carrying different voltages etc.

- Nationwide development of fragility functions for all infrastructure types and applicable to the Aotearoa-New Zealand context will assist in better quantifying potential impacts to Chatham Islands infrastructure.
- This thesis provides an assessment of tsunami impacts on infrastructure. Future research could assess: potential impacts on buildings and implications for habitability; potential impacts on people including fatalities; and capacity of the health system to respond to such event, as well as an economic assessment of loss, damage and - in particular - reinstatement costs.
- Future work could also include a cost benefit analysis to identify funding requirements and to prioritise initiatives suggested in this thesis.

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APPENDICES

Appendix A. MĀORI TERMINOLOGY

Aotearoa	Māori name for New Zealand "Traditionally known as Te Wai Pounamu (South Island) and Te Ika a Maui (North Island)." (Rayan et al., 1995, p.32).
Hapu	"kinship group, clan, tribe, subtribe - Section of a large kinship group and the primary political unit in traditional Māori society. It consists of a number of whānau sharing descent from a common ancestor, usually being named after the ancestor, but sometimes from an important event in the group's history. A number of related hapū usually shared adjacent territories forming a looser tribal federation (Iwi)" (Rayan et al., 1995, p.48).
Iwi	"Extended kinship group, tribe, nation, people, nationality, race - often refers to a large group of people descended from a common ancestor and associated with a distinct territory" (Rayan et al., 1995, p.76).
Kaitiakitanga	"Guardianship, stewardship, trusteeship, trustee… to nurture natural resources of the land and sea to benefit the next generation" (Rayan et al., 1995, p.85).
Kāinga	"Home, address, residence, village, settlement, habitation, habitat, dwelling" (Rayan et al., 1995, p.83).
Kaupapa	"Topic, policy, matter for discussion, plan, purpose, scheme, proposal, agenda, subject, programme, theme, issue, initiative" (Rayan et al., 1995, p.101).
Kaupapa Māori	Māori approach, Māori topic, Māori customary practice, Māori institution, Māori agenda, Māori principles, Māori ideology - a philosophical doctrine, incorporating the knowledge, skills, attitudes and values of Māori society
Kōrero	"Speech, narrative, story, news, account, discussion, conversation, discourse, statement, information,"(Rayan et al., 1995, p.124).
Matauranga Māori	"Māori knowledge - the body of knowledge originating from Māori ancestors, including the Māori world view and perspectives, Māori creativity and cultural practices," (Rayan et al., 1995, p.153).

Mana	"Prestige, authority, control, power, influence, status, spiritual power, charisma - mana is a supernatural force in a person, place or object. Mana goes hand in hand with tapu, one affecting the other. The more prestigious the event, person or object, the more it is surrounded by tapu and mana," (Rayan et al., 1995, p.143).
Mōteatea	"Lament, traditional chant, sung poetry - a general term for songs sung in traditional mode," (Rayan et al., 1995, p.167).
Pā	"Inhabitants of a fortified place," (Rayan et al., 1995, p.184).
Pākehā	"New Zealander of European descent - probably originally applied to English-speaking Europeans living in Aotearoa/New Zealand," (Rayan et al., 1995, p.189).
Pakiwaitara	"Legend, story, fiction, folklore, narrative, a yarn" (Rayan et al., 1995, p.190).
Pepeha	"Tribal saying, tribal motto, proverb (especially about a tribe), set form of words, formulaic expression, saying of the ancestors, figure of speech, motto, slogan - set sayings known for their economy of words and metaphor and encapsulating many Māori values and human characteristics," (Rayan et al., 1995, p.206).
Pōwhiri	"An invitation, rituals of encounter, welcome ceremony on a marae, welcome," (Rayan et al., 1995, p.221).
Pūrākau	"A myth, ancient legend, story" (Rayan et al., 1995, p.230).
Tangata Whenua	"Local people, hosts, indigenous people - people born of the whenua, i.e. of the placenta and of the land where the people's ancestors have lived and where their placenta are buried" (Rayan et al.,., 1995, p.274).
Tapu	A sacred, prohibited, restricted, protected person place or thing. "Tapu is used as a way to control how people behaved towards each other and the environment, placing restrictions upon society to ensure that society flourished" (Rayan et al., 1995, p.277).
Tohunga	"Skilled person, chosen expert, priest, healer - a person chosen by the agent of an atua and the tribe as a leader in a particular field because of signs indicating talent for a particular vocation," (Rayan et al., 1995, p.305).
Urupā	"Burial ground, cemetery, graveyard," (Rayan et al., 1995, p.328).
Waiata	"A song, chant, psalm," (Rayan et al., 1995, p.333).

Whakapapa “Genealogy, genealogical table, lineage, descent,” (Rayan et al., 1995, p.355).

Whakatauki “Proverb, significant saying, formulaic saying, cryptic saying, aphorism,” (Rayan et al., 1995, p.360). Like whakatauākī and pepeha they are essential ingredients in whaikōrero.

Whānau “Extended family, family group, a familiar term of address to a number of people - the primary economic unit of traditional Māori society. In the modern context the term is sometimes used to include friends who may not have any kinship ties to other members” (Rayan et al., 1995, p.366).

Whanaungatanga “Relationship, kinship, sense of family connection - a relationship through shared experiences and working together which provides people with a sense of belonging. It develops as a result of kinship rights and obligations, which also serve to strengthen each member of the kin group. It also extends to others to whom one develops a close familial, friendship or reciprocal relationship” (Rayan et al.,., 1995, p.366).

Whakawhanaungatanga “Process of establishing relationships, relating well to others, operationalisation of intra and extra-tribal relationships to mobilise resources and activate social support networks” (Kenney et al., 2015, p.11).

Whare “House, building, residence, dwelling, shed, hut, habitation” (Rayan et al., 1995, p.368).

Whare Wānanga “A place of higher learning - traditionally, places where tohunga taught the sons of rangatira their people's knowledge of history, genealogy and religious practices” (Rayan et al.,., 1995, p.369).

Appendix B. TSUNAMI TERMINOLOGY

Amplitude Is the peak (or trough) of the tsunami wave at some point in the ocean relative to the undisturbed sea level at the time (Figure 8.2; Goff & De Freitas, 2016).

Flow depth and Velocity The depth of a tsunami above the ground surface as it inundates the land and the velocity of the water mass (Figure 8.1, Goff & De Freitas, 2016).

Inundation height the height of a tsunami on land, above MSL i.e the sum of the inundation depth and the elevation of the point above MSL at which the flow depth is measured (Goff & De Freitas, 2016).

Inferred amplitude historic accounts mention tsunami 'wave heights'. These are termed *inferred amplitude* in this study. This is based off Thomas Ritchie's map annotation indicating the measure was taken from the water "rising in perpendicular height above the mark of high water springs on average" (Figure E.1).

Run-up height Elevation of the most landward point of the inundated area relative to the reference sea level (Figure 8.1; Goff & De Freitas, 2016).

Wave height it is the difference in elevation between the crest and the trough. It is twice the wave amplitude (Figure 8.2; Goff & De Freitas, 2016).

Wave-height-at-coast The modelled wave height for a particular coast line.

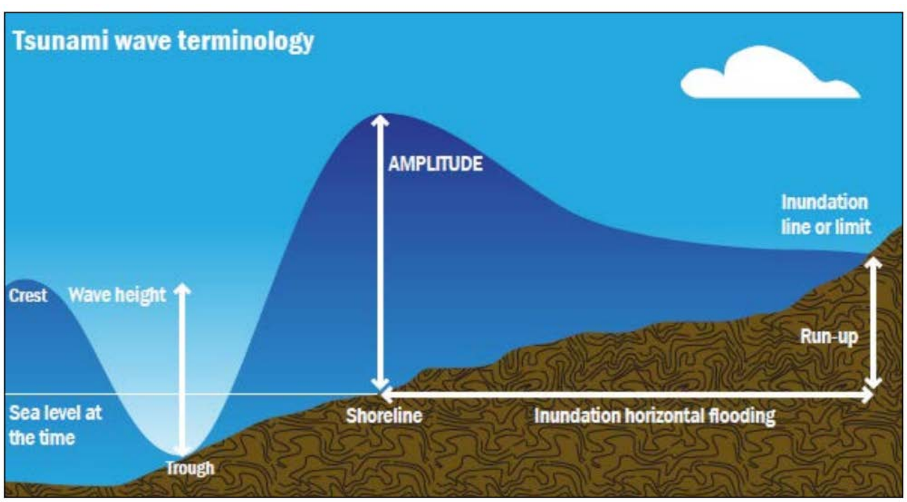

Figure B.1. Terminology relating to tsunami. Retrieved from MCDEM (2016, p.5).

Appendix C. Tsunami Warnings and Evacuation Zones

In New Zealand, evacuations are triggered by two types of tsunami warning:

1) Natural warnings such as a long or strong earthquake, weird gurgle noises, a load roar, or sudden upheaval or retreat of the sea. If these warnings are observed the public should self-evacuate all zones.
2) Official – in which case local authorities announce the zone(s) to be evacuated.

Natural warnings will need to be heeded if a tsunami is generated close to New Zealand (such as by a Hikurangi subduction zone earthquake). Local source tsunami may arrive within minutes in some places in New Zealand, thus there will not be enough time for authorities to issue an official warning.

In New Zealand, The Ministry of Civil Defence and Emergency Management (MCDEM) is responsible for the dissemination of national official tsunami notifications. MCDEM, with technical support from GNS Science, assess messages received from the Pacific Tsunami Warning Center (PTWC, based in Hawaii) and/or data received from seismic sensors and tsunami gauges around New Zealand to determine the level of tsunami threat to A-NZ and issue a warning (GeoNet, n.d-e). "Official evacuations of the general public are authorised by local authorities. They base their decision to evacuate communities on a National Tsunami Warning or Potential Threat National Advisory issued by the Ministry of Civil Defence & Emergency Management (MCDEM) in conjunction with their own local threat assessment, plans and standard operating procedures (SOPs)." (MCDEM, 2016, P.22). There are three levels of threat: No threat, Marine and Beach Threat and Marine and Land Treat which are derived based on the maximum expected wave amplitude at shorelines across the region (MCDEM, 2016).

Table C.1. Threat levels used by MCDEM when issueing an official warning. Retrieved from MCDEM, 2016, p.22

Maximum expected amplitude at shore		Threat definition
	<0.2m	No threat
	0.2-1m	Marine and Beach Threat (incl. harbours, estuaries and small boats)
	1-3m	Marine and Land Threat
	3-5m	
	5-8m	
	>8m	

Evacuation zones to assist tsunami evacuations have been developed for coastal regions around New Zealand. There are three evacuation zones for the Chatham Islands, red, orange and yellow zones:

- The red zone is evacuated during official 'beach and marine warnings' (and during 'Land and Marine warnings'). The zone includes beaches, estuaries, harbours and river mouths where strong and unpredictable currents and surges may occur during a small tsunami (< 1 m wave-height-at-coast above MSL) (CIC, n.d).
- The orange zone is evacuated during official 'Land and Marine warning'. The zone includes areas of land that could be inundated by a tsunami > 1 m (wave-height-at-coast above MSL) (CIC, n.d).
- The yellow zone is evacuated during a 'Land and Marine warning' if a tsunami > 8 m (wave-height-at-coast above MSL) is expected (CIC, n.d).
- ALL zones are evacuated if natural warnings occur without an official warning.

Evacuation zones for the Chatham Islands are provided for Waitangi, Owenga and Kaingaroa in Figures C.1-C.3. For more areas see http://www.cic.govt.nz/what-we-do/emergency-management/

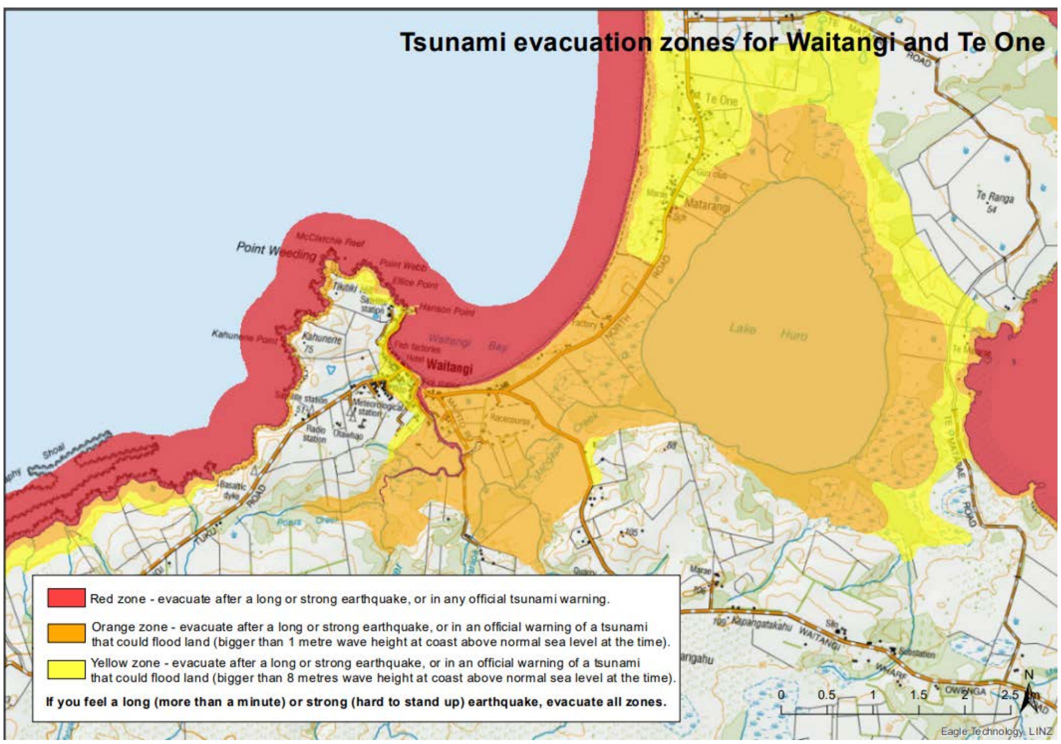

Figure C.1.Tsunami evacuation zones for Waitangi and Te One. Retrieved from CIC, n.d.

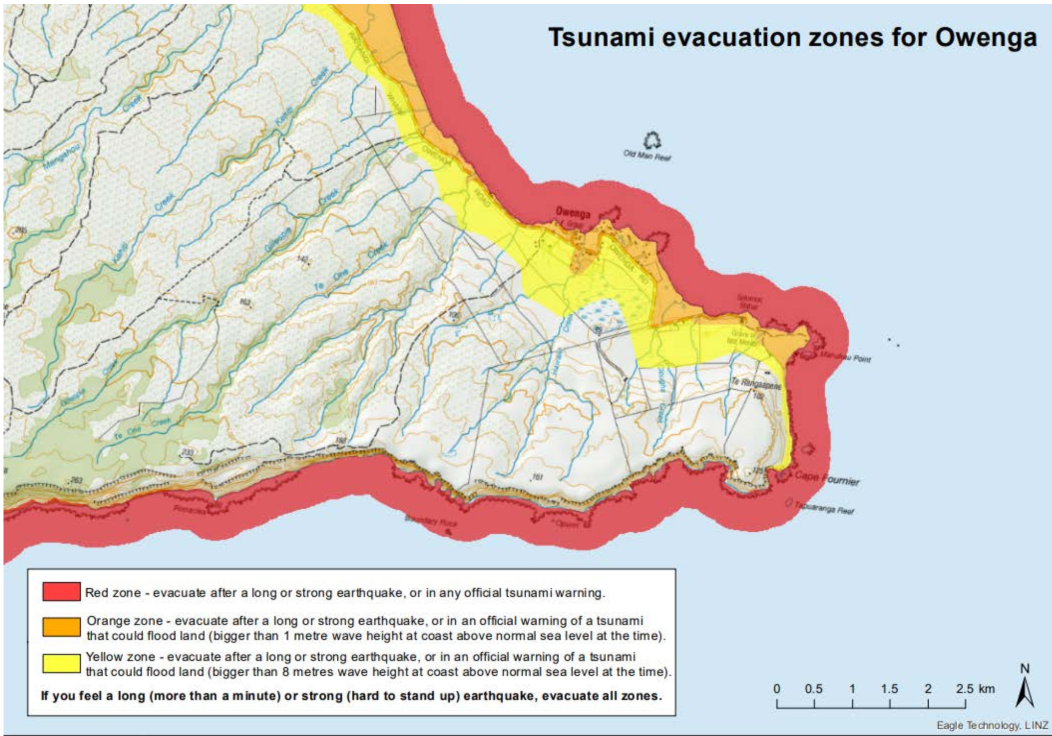

Figure C.2. Tsunami evacuation zones for Owenga. Retrieved from CIC, n.d.

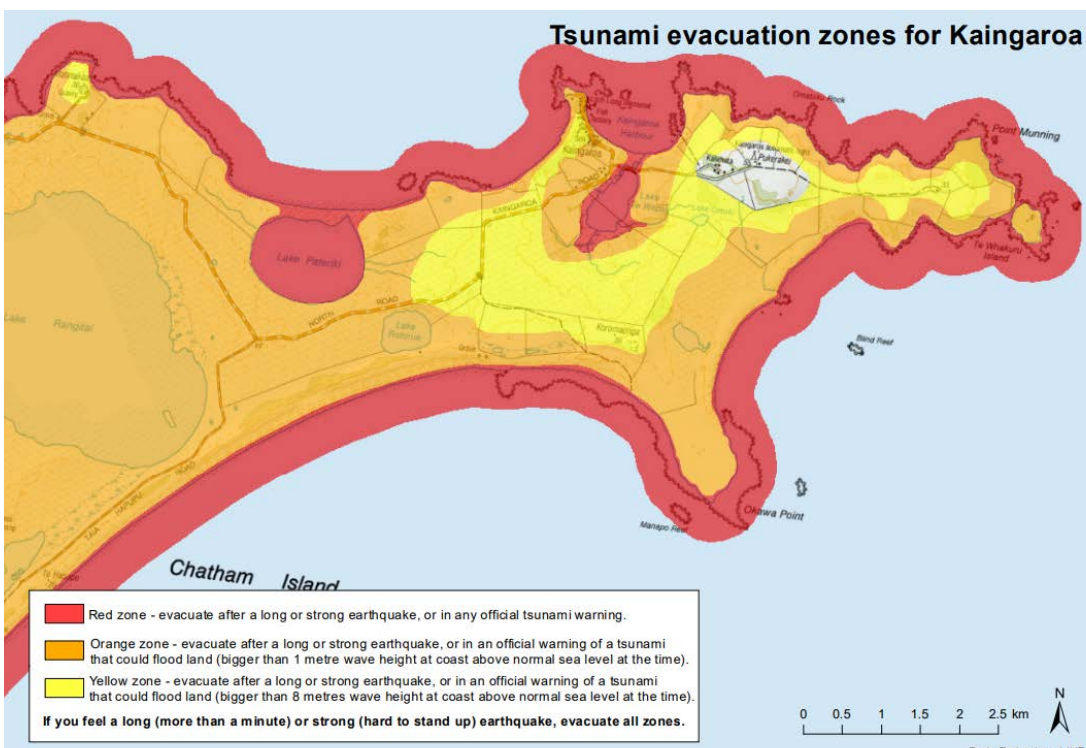

Figure C.3. Tsunami evacuation zones for Kaingaroai. Retrieved from CIC, n.d.

During a tsunami warning, boats may be advised to head to deep water of 50 m + depth. Figure C.1 indicates where the 50 m depth contour surrounds the Chatham Islands.

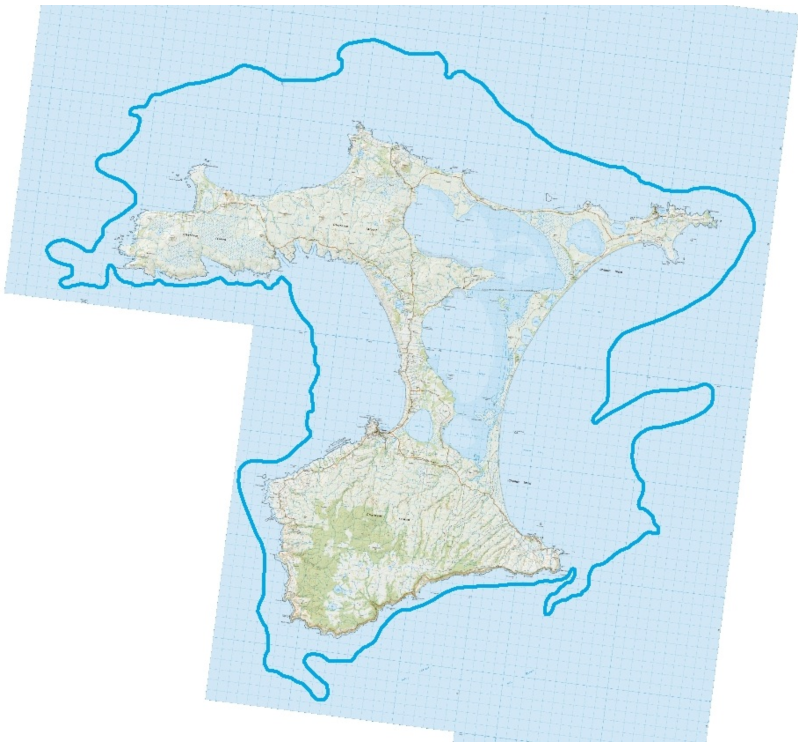

Figure C.4. 50 m depth contour around the Chatham Islands. Retrieved from H.Jack, personal communication, November, 2017

Appendix D. ETHICS APPROVALS

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

HUMAN ETHICS COMMITTEE

Secretary, Rebecca Robinson
Telephone: +64 03 369 4588, Extn 94588
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2017/11

21 April 2017

Kristie-Lee Thomas
Geological Sciences
UNIVERSITY OF CANTERBURY

Dear Kristie-Lee

The Human Ethics Committee advises that your research proposal "Investigation of Past Impacts of Tsunami on the Chatham Islands, New Zealand to Inform Disaster Risk Reduction" has been considered and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your emails of 6th and 16th April 2017.

Best wishes for your project.

Yours sincerely

pp. R. Robinson

Dr Kelly Dombroski
Deputy Chair
University of Canterbury Human Ethics Committee

University of Canterbury Private Bag 4800, Christchurch 8140, New Zealand. **www.canterbury.ac.nz**

F E S

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

HUMAN ETHICS COMMITTEE

Secretary, Rebecca Robinson
Telephone: +64 03 369 4588, Extn 94588
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2017/11 Amendment 1

12 May 2017

Kristie-Lee Thomas
Geological Sciences
UNIVERSITY OF CANTERBURY

Dear Kristie-Lee

Thank you for your request for an amendment to your research proposal "Investigation of Past Impacts of Tsunami on the Chatham Islands, New Zealand to Inform Disaster Risk Reduction" as outlined in your email dated 10th May 2017.

I am pleased to advise that this request has been considered and approved by the Human Ethics Committee.

Yours sincerely

pp. R. Robinson

Associate Professor Jane Maidment
Chair, Human Ethics Committee

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

HUMAN ETHICS COMMITTEE

Secretary, Rebecca Robinson
Telephone: +64 03 369 4588, Extn 94588
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2017/48/LR

31 July 2017

Kristie-Lee Thomas
Geological Sciences
UNIVERSITY OF CANTERBURY

Dear Kristie-Lee

Thank you for submitting your low risk application to the Human Ethics Committee for the research proposal titled "Tsunami Impact Assessment on the Built Environment of the Chatham Islands to Inform Disaster Risk Reduction Planning".

I am pleased to advise that this application has been reviewed and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your emails of 17th and 24th July 2017.

With best wishes for your project.

Yours sincerely

pp. R. Robinson

Associate Professor Jane Maidment
Chair, Human Ethics Committee

UNIVERSITY OF CANTERBURY
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Ref: HEC 2017/48/LR Amendment 1

22 September 2017

Kristie-Lee Thomas
Geological Sciences
UNIVERSITY OF CANTERBURY

Dear Kristie-Lee

Thank you for your request for an amendment to your research proposal "Tsunami Impact Assessment on the Built Environment of the Chatham Islands to Inform Disaster Risk Reduction Planning" as outlined in your email dated 20th September 2017.

I am pleased to advise that this request has been considered and approved by the Human Ethics Committee.

Yours sincerely

pp. R. Robinson

Associate Professor Jane Maidment
Chair, Human Ethics Committee

Appendix E. SUPPORTING INFORMATION FOR HISTORICAL EVENT INVESTIGATION

E.1. Photographs and Maps used to Evaluate Inundation Extents and Digitise Assets

1868 Event

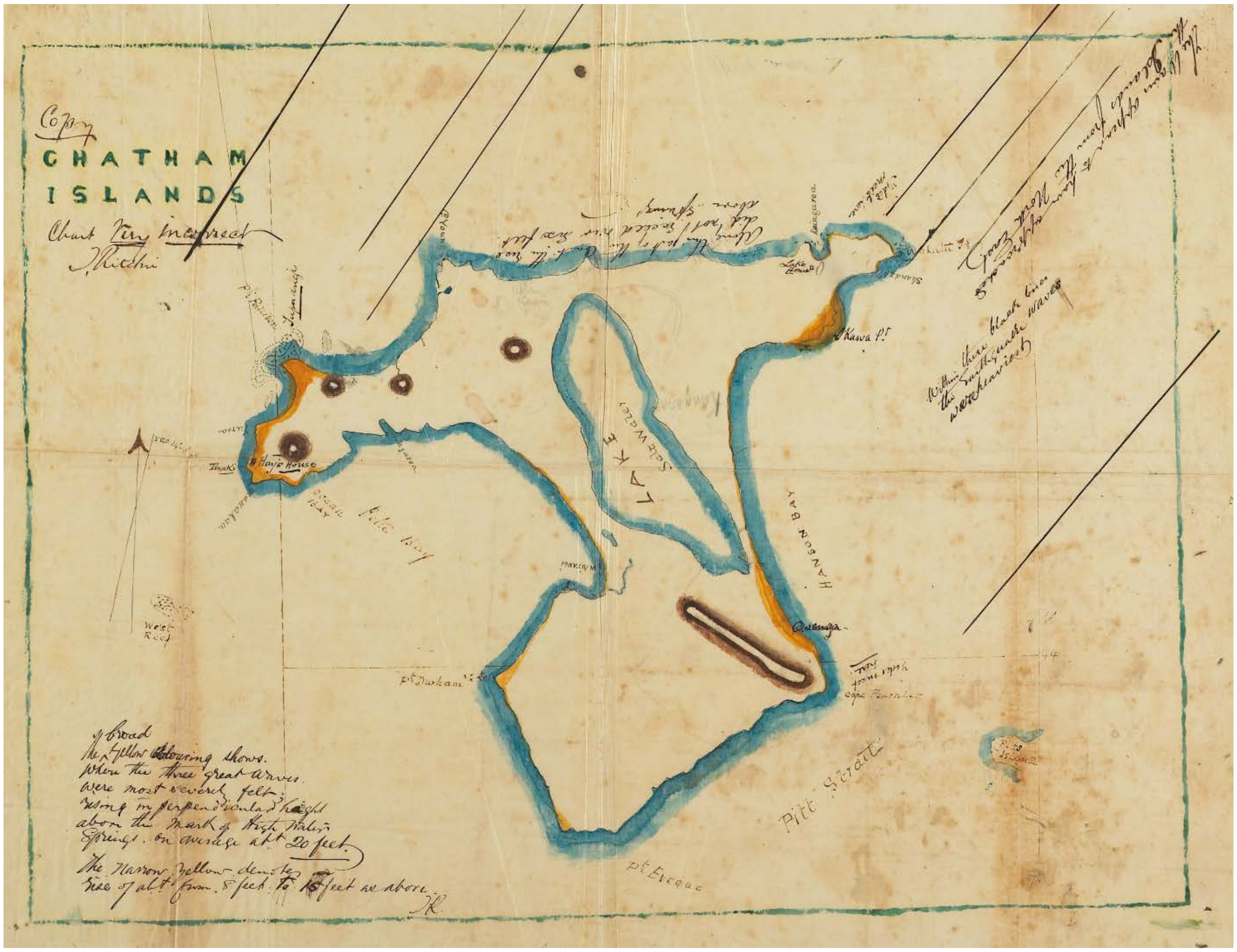

Figure E.1. Map of 1868 tsunami inundation (yellow) produced by local run holder and trader Thomas Ritchie included in a letter sent to Charles Heaphy dated 29 September 1868. Transciption of text at the top "Along this part of the coast the rise did not exceed over 6 feet above springs." Transcription of Bottom Left: "The broad yellow colouring shows where the three giant waves were most severely felt; rising in perpendicular height above the mark of high water springs on average about 20 feet. The narrow yellow denotes a rise of about 8-15 feet as above." Image courtesy of National Museum of New Zealand Te Papa Tongarewa (MU000243/005/0001; Re: Earthquake Wave at the Chatham Islands; 1868-1869).

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1868 Waitangi

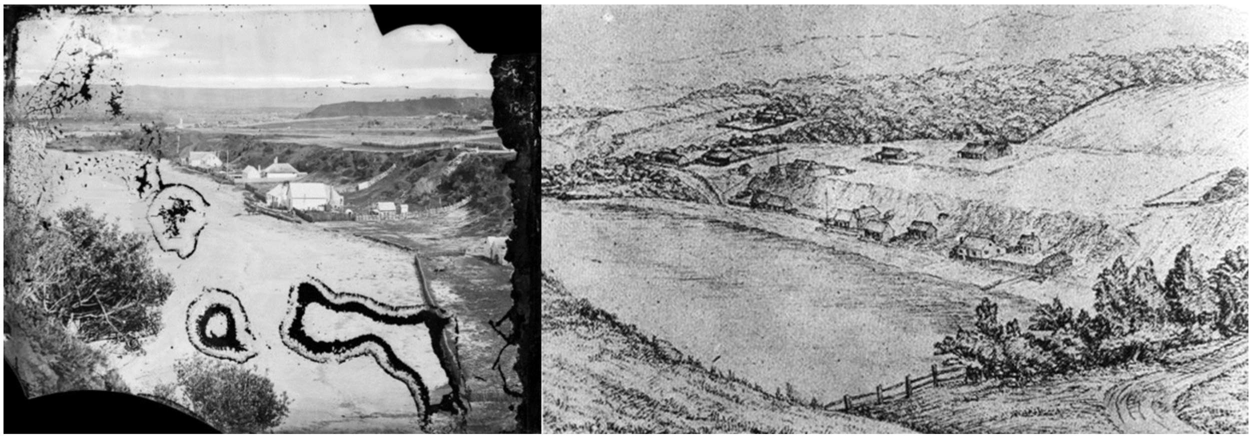

Figure E.2. Left: Waitangi 1877, retrieved from Alfred (1866-1899). Right: Sketch of Waitangi 1868 by Stephenson Percy Smith, Retrieved from Richards & Carter, 2009, p.6.

Figure E.3. Nairn River, Waitangi, looking towards Maipito and Nairn River House, sometime between 1844-1922. Photograph taken by (Romeril, 1844-1922). This photograph may have been taken following the tsunami event, or possibly after a large flood: Maipito appears to be inundated by water, the Waitangi bridge is absent apart from some piles and the river bank is scoured. Further investigation is required.

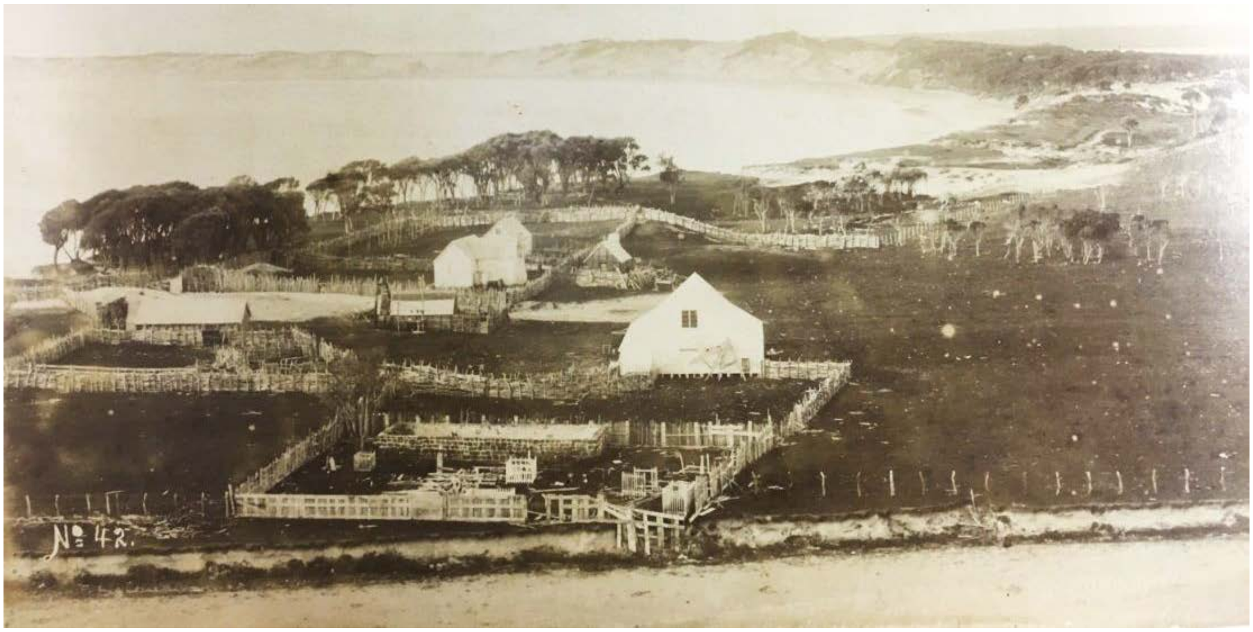

Figure E.4. Waitangi Pa sometime between 1844-1922. Photograph taken by (Romeril, 1844-1922). This photograph may have also been taken following the tsunami, or following a large storm or flood: the river bank is scoured, there are debris scattered on the ground, a fence appears to be hanging off the side of the river bank, and a brick house foundation is 'topless', there also appears to be erosion of the sand dunes along the coast line. Further investigation is required.

Figure E.5. Waitangi Beach sometime between 1844-1922. Photograph taken by (Romeril, 1844-1922).

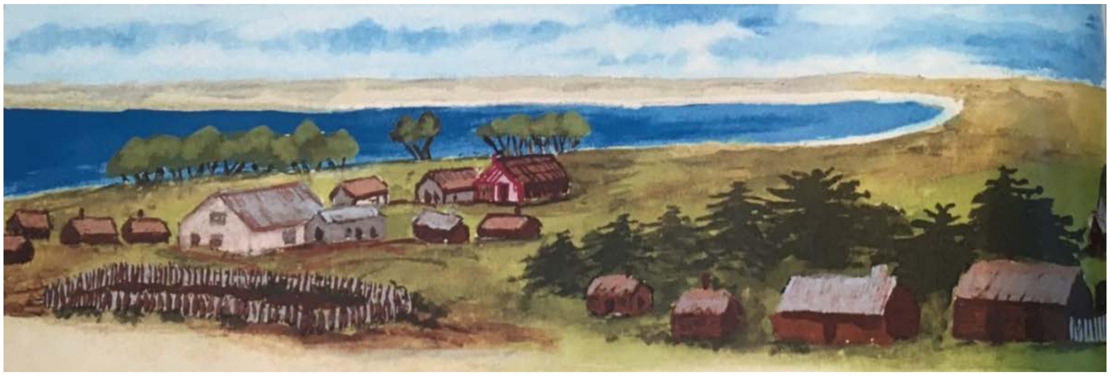

Figure E.6. Painting of Waitangi Pa 'about 40 years ago' (before 1939). Retrieved from Pupils of Kairakau School (1939, p.67).

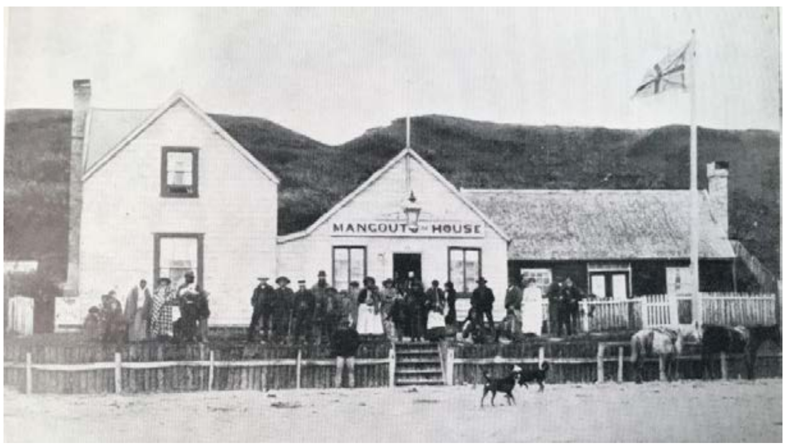

Figure E.7. Mangouts House located in Waitangi Harbour (which was not damaged in the 1868 tsunami) photographed between1880-1895. Retrieved from Simpson (1950) p.141.

Figure E.8. Beamish's accommodation house post tsunami in 1872 or early 1873. Retrieved from University of Otago Library (n.d).

Figure E.9. Nairn House 1991 courtesy of Pam Bain. Retrieved from Heritage New Zealand.

1868 Owenga

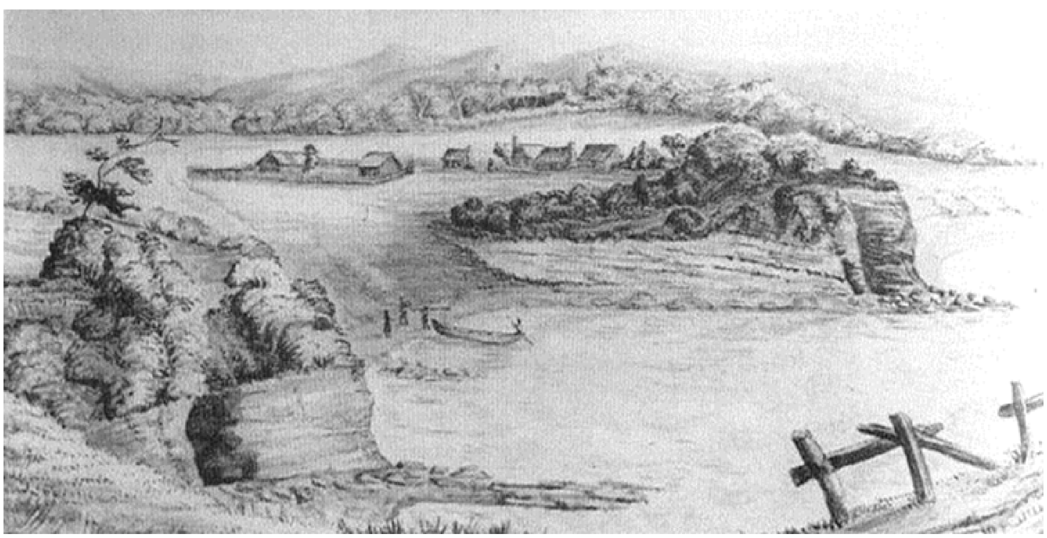

Figure E.10. Sketch of Owenga 1868 by Stephenson Percy Smith. Retrieved from Richards & Carter, 2009, p.6.

1868 Kaingaroa

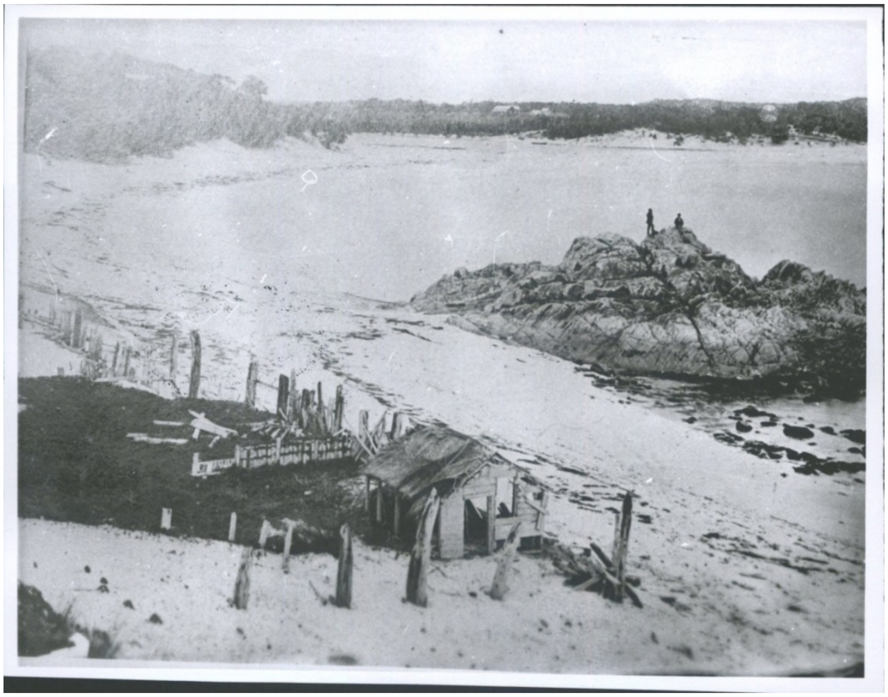

Figure E.11. Kaingaroa landing Bay, and remnants of the old Pa. Retrieved from Retrieved from University of Otago Library (n.d-b).

1924 Pitt Island – Flower Pott

Figure E.12. Flower Pott sometime between 1844-1922. Photograph taken by (Romeril, 1844-1922).

1924 Kaingaroa

Figure E.13. Top: photograph of Kaingaroa in 1979, area left of the road has since been eroded. Houses located on the left side of the wharf, proximal to the wharf no longer exist. Retrieved from Barker Bros. Ltd (2002). Bottom: Google Earth 2015 imagery of Kaingaroa, yellow, pink and red reference points are provided to show erosion of the coastline. Considering the differences in 36 years between 2015 – 1979, it can be assumed substantial land has eroded since the 1924 coastline.

Figure E.14. Rusted steel pipes and braces that were damaged in the 1924 event.

1960 Waitangi

Figure E.15. Dray carts down Waitangi Beach. Retrieved from Chatham Islands Museum (n.d).

Figure E.16. Waitangi Wharf 1907. Retrieved from Chatham Islands Museum (n.d).

Figure E.17. Waitangi, date unknown. Chatham Islands Museum (n.d).

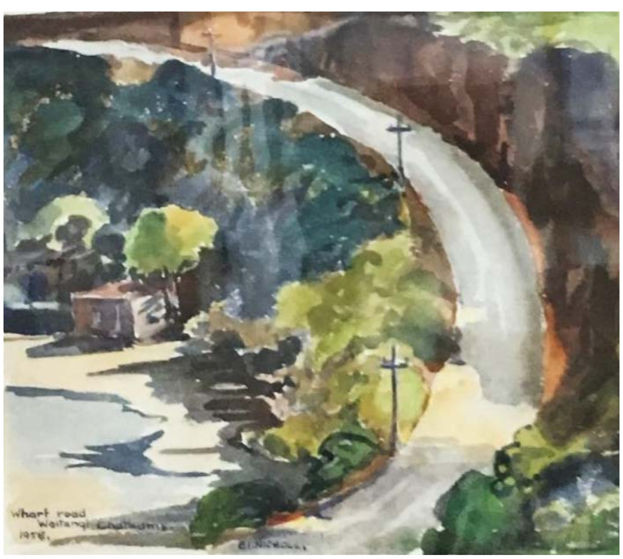

Figure E.18. Painting of Waitangi Wharf Rd and Fisherman's Hut. Retrieved from Chatham Islands Museum (n.d).

E.2. Advertising to Recruit Participants

Figure E.19. Screenshot of Facebook post to 'Chatham Islander's Worldwide' page to recruit participants.

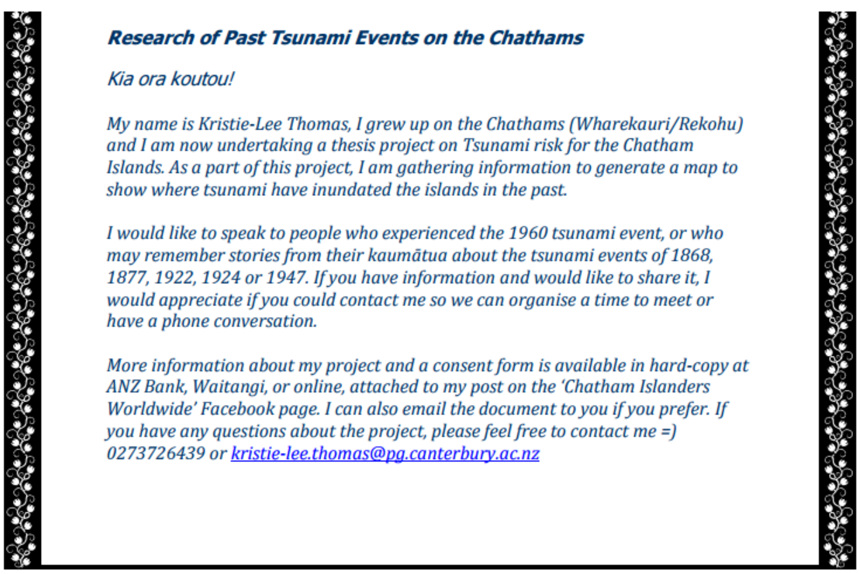

Figure E.20. Advertisement to recruit participants included in Chatham Islands Community Focus newsletter.

Tsunami Research - Kristie-Lee Thomas

Ka ketekete te toroa,
Ka hakoko te Taiko me te Tītī
ka umere ahau tīhei Mauriora
Ko Pipitarawai tōku maunga,
Ko Mangatukarewa tōku awa,
Ko Rangimatawai tōku waka,
Ko Pā Tangaroa pā kāinga,
Ko Ngāti Mutunga tōku iwi,
Nō Wharekauri ahau,
Engari ko Ōtautahi tōku Kāinga īnāianei,
Ko Te Whare Wānanga o Waitaha tōku puna Mātauranga,
Ko Joe rāua Ko Miriam ōku tāua,
Ko Joseph Thomas tōku matua,
Ko Shelly Thomas tōku whaea,
Ko Jake Thomas tōku tungāne,
Ko Kristie-lee tōku ingoa,
Ko Thomas te ingoa o tōku whānau,
Nō reira tēnā koutou tēnā koutou tēnā koutou katoa.

My name is Kristie-Lee Thomas. I am currently doing my Masters in Disaster Risk and Resilience at the University of Canterbury. As part of my Masters programme I will be undertaking a dissertation which is a 3-month research project over this summer and then a 12-month thesis starting next year. For these research projects I will be contributing to current tsunami risk evaluations for the Chatham Islands working along-side the community, local Iwi, the Chatham Islands Council, the Chatham Islands Enterprise Trust, ECan and NIWA.

For my dissertation I am investigating the impact of past tsunami on the Chatham Islands to gain a better understanding of tsunami hazard and to assist in evacuation planning. For my dissertation I will also be assessing the exposure of lifelines and infrastructure to tsunami hazard. I am still in the process of scoping my thesis topic for 2017 - 2018.

If you have any photos, diaries, or letters that record past tsunami on the Chathams, I would be very interested in seeing them and would appreciate if you could contact me on 03 359 0367 or by email: klt61@uclive.ac.nz. If you have any queries relating to my research, please also feel free to contact me. I look forward to hearing from you.

Tsunami Meeting 17th November

A community meeting was held on the 17th of November 2016 with presentations from tsunami scientists from Tohoku University in Japan, the University of New South Wales, and NIWA who have investigated past tsunami events in the sedimentary record at Okawa Point and Cape Pattison. Helen Jack from ECan also presented some tsunami modelling results for the Chatham Islands, discussed the development of evacuation zones for the Chathams and gave some evacuation advice. These presentations were followed by questions and discussions. Below I have provided a summary of information presented at this meeting:

Tsunami Hazard on the Chatham Islands:

- Tsunami generated from distant sources such as South America are expected to arrive within 10 - 15 hours.
- Tsunami generated from regional sources such as the Hikurangi or Kermadec Troughs off the east/north coast of New Zealand could arrive in as little as 1.5 hours.
- When a tsunami arrives, it arrives as a series of surges. The first wave may not be the largest and time intervals between arriving tsunami waves may vary from minutes to hours.
- Tsunami have impacted the Chatham Islands in 1604, 1868, 1877, 1924, 1947 and 1960.

Current Progress:

- Tsunami scientists from Tohoku University in Japan, the University of New South Wales, and NIWA have identified physical evidence of the 1604 and 1868 tsunamis in the sedimentary record at Okawa Point and Cape Pattisson.
- Tsunami inundation modelling has been carried out for a Chile tsunami and Hikurangi Trough tsunami for the Chatham Islands. Evacuation zones based on this information are currently being developed by the Chatham Island Council and Environment Canterbury and they hope to have these drafted by February 2017 for community engagement.

What you can do:

- Make a family evacuation plan (where you will meet, where you will go and what you will take) and have an evacuation kit ready. For more information, see http://www.getthru.govt.nz/
- Make a business evacuation and emergency shut-down procedure plan, for more information see http://getthru.govt.nz/how-to-get-ready/get-your-business-ready/
- If you have internet, you can access the 'CIC Emergency Management' Facebook page to keep updated in emergency situations (even if you do not have a Facebook account).
- If you have Facebook you can also keep updated in emergencies by checking the 'Chatham Islanders Worldwide' page.
- If you do not have internet, listen to VHF Radio broadcasts for tsunami warnings.

Evacuations:

- **Do not wait for official warnings**, if you are in low-lying areas and aware from other sources that a tsunami is coming or feel a strong (can't stand up) OR long (more than a minute) earthquake, **self-evacuate to high ground and stay evacuated** until advised by authorities to return home. Other natural warnings include the sea retreating, the sea rising in an unusual way or an unusually load roar from the sea.
- If there is a tsunami warning, **STAY AWAY FROM THE BEACH** DO NOT go sightseeing, DO NOT gather seafood or do any other beach and marine activities. By doing so, you are not only endangering your own life, but you are also endangering the lives of emergency personnel. Also **STAY AWAY from rivers, estuaries, and lakes.**
- **Boats**: If there is time before tsunami arrival (for example, if it is coming from South America), or if boats are out fishing when a tsunami warning occurs, it is advised that they travel out to deep water (more than 50m depth and away from the coastline) and be prepared to stay out for several hours. Tsunami arrive as a series of surges, the first wave may not be the largest.

Figure E.21. Advertisement to recruit participants or tsunami related material included in Te Pānui o Ngāti Mutunga o Wharekauri Iwi (quarterly panui to 31 December 2016).

E.3. Interview Guideline Questions

The following topics were used to guide the semi structured interviews with Tangata Whenua:

- 1868/1877/1924/1946/1947 tsunami/s,
    - Asked question in a local context such as: do you recall the Waitangi West 'Tidal Wave'? Do you recall the 'tidal wave' that washed away the Kaingaroa Dam during the Cod boom days?
- Time of arrival, wave height, number of waves that arrived, duration of tsunami/unusual tide.
- Observations of abnormal sea activity related to tsunami (such as the sea retreating).
- Any types and sources of warning.
- Locations and extent of tsunami inundation (referencing aerial photographs).
- Any direct impacts to society, such as damage to buildings/infrastructure, people or property and locations of these impacts (referencing aerial photographs).
    - Used this opportunity to identify locations of assets recorded in documented accounts and to identify exposure at the time of the event.
- Any indirect impacts to society, including disruption of economic activities (e.g. fishing), disruption of critical infrastructure (referencing aerial photographs).
- Any impacts on the environment e.g. strange tides, increased erosion, change in the bathymetry (referencing aerial photographs).

A3 aerial photographs (Google Earth 2015 imagery) were printed for most coastlines around the Chatham Islands. These maps were used to reference locations mentioned during the interview and to draw inundation extents. Figure E.22 provides an example.

Figure E.22 Ariel photograph used to locate assets and inundation extent (marked by red whiteboard marker). Photograph has been edited to make red marker more identifiable.

Appendix F. Supporting Impact Assessment Information

F.1. Evaluating Levels-of-Service from Damage States

The following tables (Tables F.1-F.8) were formed using the methods described in Section 5.3.4 and were used to generate the scenario impacts listed in Section 5.4.3. The vulnerability matrix for bridges is located in the main body of the thesis as an exemplar (Section 5.4.2), the rest are provided here.

Private property including fishing vessels are not included in the vulnerability matrices as these were excluded from the scenario for sensitivity reasons. If components are not included in the matrices, it is because Williams (2016) damage matrix does not provide a damage matrix for that component.

Table F.1. Vulnerability matrix for ports. Derived from Horspool & Fraser (2016), Blake et al., (2017), Robinson et al., (2014), Williams (2016), Williams (2016a), and Turnbull & Hughes (2017).

	Damage Type			Damage State		Level-of-Service	
	Flow Depth (m)	**Probability of damage**	**Description**	**Metric Value**	**Description**	**Metric Value**	**Functionality State**
Wharves	0	None	No damage	DS0	Promptly usable without repair or clean up	LS1	Full service
	<0.5	Negligible-low	Debris strikes, scour of foundations	DS1	Reusable after minor repairs or clean up	LS2	Partial service until minor repairs/clean up
	0.5-2.0	Medium	Sediment and debris deposition, debris strikes, scour of seabed, debris in waterways, scour of foundations, lifting of wharf slabs if poorly tied	DS2	Some structural damage, moderate sediment coverage and flooding, possibly reusable after repair and clean up	LS2	Partial service, may be able to still use parts of the wharf under load restrictions
	>2.0	High	Aggradation/erosion of sea bed, separation of deck slabs from footings, removal of concrete blocks, subsidence, collapse, complete washout, debris in waterways	DS3	Mostly irreparable structural damage, require demolition and rebuilding	LS3	No service, wharf not operational
Fuel Pipe	0	None	No damage	DS0	Promptly usable without repair or clean up	LS1	Full service
	<0.5	Negligible	Negligible damage	DS1	Usable, but would eventually require minor repairs or clean up	LS1	Full service
	0.5-2.0	Low-medium	Scour and exposure of buried pipes, utility bridges severed, pipes attached to mobilised tanks severed, debris strikes	DS2	Moderate damage, bowsers and pipe connections need to be fixed, pipes needed to be welded together, pipes possibly reusable after repair and clean up	LS3	No Service until moderate repairs and clean up
	>2.0	Medium	Scour and exposure of buried pipes, utility bridges severed, pipes attached to mobilised tanks severed, debris strikes decoupling, fire	DS3	Major irreparable structural damage, require new pipeline, bowsers and connections	LS3	No Service

Electricity line to wharf	0	None	No damage	DS0	Promptly usable without repair or clean up	LS2	Full service
	<0.5	Negligible-low	Water infiltration of compromised cable housing	DS1	Cables would need to be replaced	LS3	No service
	0.5-2.0	low	Scour at building entry points, scour of backfill, exposure, water infiltration of compromised cable housing , ducting & cables across waterways or below bridges severed	DS2	Cables and connectors would need to be replaced	LS3	No Service
	>2.0	Low-medium	Scour at building entry points, scour of backfill, exposure, water infiltration of compromised cable housing , ducting & cables across waterways or below bridges severed, ducting & cables severed	DS3	Cables and connectors would need to be replaced	LS3	No Service
Water pipe to wharf	0	None	No damage	DS0	Promptly usable without repair or clean up	LS1	Full Service
	<0.5	Low	Minor siltation	DS1	Minor repairs and cleaning of pipes	LS2	Partial service (reduced flow and sediment infiltration)
	0.5-2.0	Low	Scouring, exposure and floatation, debris strikes, damage at bridges	DS2	Major pipe repairs and sections of new pipe required due to major damage.	LS3	No Service
	>2.0	Medium	Scouring, exposure and floatation, debris strikes, damage at bridges	DS3	New pipeline required due to severe damage	LS3	No Service
Buildings	0	None	No damage	DS0	Promptly usable without repair or clean up		
	<0.5	Low-medium	Water damage to interiors & stored goods	DS1	reusable after minor repairs and/or cleaning, most contents require		

					replacement	
	0.5-2.0	High	Water damage to interiors & stored goods, short circuiting of electrical components, washout of lightweight structures (timber and light steel)	DS2	Some structural damage, moderate sediment coverage and flooding, possibly reusable after repair and clean up. Most, if not all contents require replacement	
	>2.0	High	Water damage to interiors & stored goods, short circuiting of electrical components, washout of lightweight structures and non-structural damage reinforced concrete buildings	DS3	Mostly irreparable structural damage, building has either collapsed, overturned, washed away or only the foundation remains.	
Seawall	0	None	No damage	DS0	Seawall fit for purpose without repair	
	<0.5	Negligible	Negligible damage	DS0	Seawall fit for purpose without repair	
	0.5-2.0	Medium	Scour of base and foundations, washout or movement of concrete or boulders	DS1/2	Seawall not fit for purpose due to structural damage, repairs or rebuilding required	
	>2.0	High	Liquefaction and scour of foundations, tilting of concrete blocks or boulders, removal of materials - especially on backside & wall breaks	DS3	Seawall not fit for purpose due to severe structural damage, major repairs or rebuilding required	
Breakwater	0	None	No damage	DS0	Breakwater fit for purpose without repair	
	<0.5	Negligible	Negligible	DS0	Breakwater fit for purpose without repair	
	0.5-2.0	Medium	Scour of base and foundations, some partial washout	DS0	Breakwater fit for purpose without repair	
	>2.0	High	Liquefaction and scour of base and foundations, washout. Mobilisation of Xblocs (KL opinion)	DS3	Breakwater not fit for purpose	
Vessels	0	None	No Damage			
	<0.5	Negligible - low	Broken moorings, debris strikes, impact damage			

	0.5-2.0	Medium-high	Broken moorings, debris damage, impact damage, floated inland
	>2.0	High	Broken moorings, debris damage, impact damage, floated inland, capsized, submerged
Containers	0	None	No damage
	<0.5	Negligible	Negligible damage
	0.5-2.0	Medium	Floating of container, impact damage, debris strikes, water & impact damage to goods, dangerous goods exposed, carried inland
	>2.0	High	Floating of container, carried inland, impact damage, debris strikes, water & impact damage to goods, dangerous goods exposed, distorted, crushed
Harbour navigation - Seabed	Erosion and scouring of seabed; Sedimentation and siltation; Disturbance of marine habitat		
Harbour navigation - Shoreline	Loss of coastlines, dunes, soil and beaches due to erosion and scouring; Uprooting of trees; Disturbance of terrestrial habitats; Fish and shellfish thrown ashore with possible consequent contamination; Contamination of groundwater; Burial of debris on the shoreline from sedimentation		

Figure F.1. Examples of port damage states. Top Left: Current state of Owenga Wharf with no tsunami damage (DS0). Top Right: Gisborne Wharf at DS1 following impact from the 1947 tsunami, retrieved from GNS Science (n.d-b). Bottom Left: Damage to Omoe Port (DS2) following impact from the 2011 GEJ tsunami, retrieved from the Pacific Earthquake Engineering Research Center (n.d). Bottom Right : Sendai Shiogama Port following impact from the 2011 GEJ tsunami, retrieved from PARI, 2011.

Table F.2.Vulnerability Matrix for roads. Derived from Blake et al., (2017), Horspool & Fraser, (2016), Mason & Brabhaharan (2015), Robinson et al., (2014),Williams (2016), Williams, (2016a).

Damage Type			**Damage State**		**Level-of-Service**	
Flow Depth (m)	**Probability of damage**	**Description**	**Metric Value**	**Description**	**Metric Value**	**Functionality State**
0	None	No damage	DS0	Promptly reusable without repair or cleaning	LS1	Full access, no restrictions
<0.5	Low	Silt and light debris coverage, ponding	DS1	Non structural damage, minor damage to road surface due to flooding and debris, reusable after minor repairs and/or cleaning	LS2	Full access, 30km speed restriction
0.5-2.0	Medium	Debris and sediment coverage, scour of weak base materials and near culverts, removal of signage and markings, ponding	DS2	Some structural damage, moderate sediment coverage and flooding, major damage to one lane/half the road, possibly reusable after repair and clean up	LS2	Restricted access to off-road vehicles (e.g. 4wd vehicles, quad bikes), 30km speed restriction
>2	Medium-high	Debris strikes , scour of base materials and near culverts, lifting of carriage-way, removal of barriers and signage, cracking of pavement, liquefaction of base materials, ponding, debris and sediment coverage	DS3	Major damage to whole carriageway. Mostly irreparable structural damage, require rebuilding of road base, new seal and signage, replacement of culverts	LS3	Road unusable, restricted access to heavy vehicles/earth moving machinery (e.g diggers)

Figure F.2. Examples of Road damage States, adapted from Williams (2016). Top Left: road in Coquimbo with little damage from the 2015 Illapel Tsunami, retrieved from Williams, 2016, p.48. Top Right: Road in Kos with minor debris, sediment and ponding of water on the road, retrieved from Robinson & Robinson, 2017. Bottom Left: structural damage to a road in Coquimbo following impact from the 2015 Illapel Tsunami, Retrieved from Williams, 2016. Bottom Right : wash away of a road lane in Coquimbo following impact from the 2015 Illapel Tsunami, Retrieved from Williams, 2016

Table F.3. Vulnerability matrix for electricity. Derived from Deligne et al., (2017), Horspool & Fraser, (2016), Williams (2016).

	Damage Type			Damage State		Level-of-Service	
	Flow Depth (m)	**Probability of damage**	**Description**	**Metric Value**	**Description**	**Metric Value**	**Functionality State**
Overhead lines	0	None	No damage	DS0	No damage	LS1	Full service
	<0.5	Negligible	Negligible damage	DS1	Negligible - minor damage to overhead lines, may be some increased tension due to scour of poles and slight leaning (KL)	LS1	Full service, may need minor repairs to poles
	0.5-2.0	Low-medium	Lines severed from pulling of utility poles, shorting of inundated transformers	DS2	Moderate damage, would require wire joiners, possibly replacement some lines and some transformers	LS3	No Service
	>2	High	Debris strikes, lines severed and washed away if reached by water, short circuiting, water damage, shorting of transformers	DS3	Major damage, require replacement of poles, lines and transformers	LS3	No service
Power poles	0	None	No Damage	DS0	No damage	LS1	Full service
	<0.5	Negligible	Negligible	DS1	Negligible damage	LS1	Full service
	0.5-2.0	Low-medium	Some debris strikes causing leaning or washout, scour of foundations (more if set in soil), shorting of inundated transformers	DS2	Minor damage to pole and overhead services. Pole may be leaning and services most likely have experienced water damage	LS3	No Service Minor repairs needed and pole realignment. Some components may need replacing due to salt-water intrusion.
	>2	High	Debris strikes causing leaning or washout, scour and liquefaction of foundations (more if set in soil), shorting of inundated	DS3	Complete damage, pole and services washed away	LS3	No service, replacement required

			transformers, tilting, shearing of base, washout				
Buried lines	0	None	No damage	DS0	No damage	LS1	Full service
	<0.5	Negligible-low	Water infiltration of compromised cable housing	DS1	Minor damage, would require replacement of some transformers and cable	LS3	No Service
	0.5-2.0	Low	Scour at building entry points, scour of backfill, exposure, water infiltration of compromised cable housing , ducting & cables across waterways or below bridges severed	DS2	Moderate damage, would require replacement of transformers, cable and casing across bridges	LS3	No Service
	>2	Low-Medium	Scour at building entry points, scour of backfill, exposure, water infiltration of compromised cable housing , ducting & cables across waterways or below bridges severed, ducting & cables severed	DS3	Major damage, Moderate damage, would require replacement of transformers, cable and casing across bridges	LS3	No service

Figure F.3. Examples pf power pole damage state. Top Left: Power poles in Waitangi, Chatham Islands, New Zealand. Top Right: DS1 power poles following impact from 1964 Prince William Sound Tsunami, retrieved from Wikiwand, n.d. Bottom Left: DS2 power pole following impact from the 2011 GEJ Tsunami, retrieved from Fisheries and Oceans Canada, n.d. Bottom Left: DS3 power pole, destroyed by the 2011 GEJ Tsunami, retrieved from Kuyama, 2011.

Table F.4. Vulnerability matrix for petroleum. Derived from Horspool & Fraser, (2016) and Williams , (2016).

	Damage Type			**Damage State**		**Level-of-Service**	
	Flow Depth (m)	**Probability of damage**	**Description**	**Metric Value**	**Description**	**Metric Value**	**Functionality State**
Tanks	0	None	No damage	DS0	No damage	LS1	Full service
	<0.5	Negligible	Negligible damage	DS1	Negligible – minor damage, minor sediment/debris clean up around tanks or from bunding	LS1	Full service
	0.5-2.0	Negligible-Low	Debris strikes, buckling of tank base, lifting of empty or small tanks, scour of foundations	DS2	Moderate damage, require cleanup of sediment and debris, repositioning of moved tanks, bowsers may need to be fixed, infill around foundations, and fixing parts of the tank that have been struck by debris.	LS2	Partial service, may be able to extract fuel from tanks depending on impact to pipe connections and bowsers.
	>2	Medium-High	Sliding, overturning , debris strikes, scour & liquefaction of foundations floating, impact damage, crushing, loss of fuel, fires	DS3	Major damage, require cleanup of sediment and debris, drainage of remaining fuel into drums, cleanup of leaked fuel, removal of damaged tank and foundations to rebuild. May be able to reuse tank and foundations after repairs. Replacement of damaged pipes and bowsers and repair of bunding	LS3	No Service
Pipes	0	None	No damage	DS0	No damage	LS1	Full Service
	<0.5	Negligible	Negligible damage	DS1	Negligible-minor damage, may require cleanup of sediment and debris around pipes and bowsers	LS1	Full Service

	0.5-2.0	Low-Medium	Scour and exposure of buried pipes, utility bridges severed, pipes attached to mobilised tanks severed, debris strikes	DS2	Moderate damage, require cleanup of sediment and debris, welding of severed pipe or replacement of some pipeline before delivery of fuel restored	LS3	No service
	>2	Medium	Scour and exposure of buried pipes, utility bridges severed, pipes attached to mobilised tanks severed, debris strikes decoupling, fire	DS3	Major damage, require cleanup of sediment and debris, cleanup of leaked fuel, removal and replacement of damaged pipeline. May be able to weld some sections of pipe together	LS3	No service

Table F.5. Vulnerability matrix for sewerage. Derived from Horspool & Fraser (2016) and Williams (2016).

	Damage Type			Damage State		Level-of-Service	
	Flow Depth (m)	**Probability of damage**	**Description**	**Metric Value**	**Description**	**Metric Value**	**Functionality State**
Pipes	0	None	No damage	DS0	No damage	LS1	Service
	<0.5	Low	Silt infiltration	DS1	Minor damage, may require cleanup of sediment and debris around pipes and bowsers	LS2	Partial service with leakage
	0.5-2.0	Low	Siltation, scour of weak backfill, exposure, bending, debris strikes, damage to water meters, utility bridges severed by debris strikes	DS2	Moderate damage, require cleanup of sediment and debris, welding of severed pipe or replacement of some pipeline before delivery of fuel restored	LS3	No service
	>2	Medium	Scour, bending and breakage, decoupling & exposure, fracturing, siltation, blockage, utility bridges severed	DS3	Major damage, require cleanup of sediment and debris, cleanup of leaked fuel, removal and replacement of damaged pipeline. May be able to weld some sections	LS3	No service

					of pipe together		
Pumping Stations	0	None	No damage	DS0	No damage	LS1	Service
	<0.5	Negligible-Low	Inundation of some electrical components	DS1	Minor damage	LS2	Partial service, pumping station will still store sewage, ability to pump may be impaired
	0.5-2.0	High	Contamination & failure of electrical & pumping equipment, sediment & debris cover, debris strikes, damage to filters	DS2	Moderate damage	LS3	No service, sewage stored in tank but pump requires repair or replacement of electrical components
	>2	High	Contamination & failure of electrical & pumping equipment, sediment & debris cover, debris strikes, structural collapse, equipment washout, often only in-ground equipment remaining	DS3	Major damage	LS3	No service, sewage leakage due to tank or pipe damage pump requires repair or replacement of electrical components
Septic Tanks	0	None	No damage	DS0	No damage	LS1	Full service
	<0.5	Low	Salt water contamination	DS1	Minor damage	LS2	Partial Service
	0.5-2.0	Low	Floating of exposed low volume polyurethane tanks, sedimentation, scour of weak backfill	DS2	Moderate damage	LS2	Partial Service
	>2	Medium	Sediment infill, scour, floating of low volume tanks	DS3	Major damage	LS3	No service

Treatment Facilities	0	None	No damage	DS0	No damage	LS1	Full service
	<0.5	Medium-High	Salt water contamination	DS1	Minor damage	LS2	Partial service
	0.5-2.0	High	Siltation, erosion of embankments, inundation of machinery, water damage of structure interiors, salt water contamination of filters pumps & ponds	DS2	Moderate damage	LS3	No service
	>2	High	Siltation, erosion of embankments, inundation of machinery, water damage of structure interiors, salt water contamination of filters pumps & ponds, washout	DS3	Major damage	LS3	No service

Table F.6. Vulnerability matrix for potable water. Derived from Horspool & Fraser, (2016), Robinson et al., (2014) Williams, 2016.

	Damage Type			**Damage State**		**Level-of-Service**	
	Flow Depth (m)	**Probability of damage**	**Description**	**Metric Value**	**Description**	**Metric Value**	**Functionality State**
Pipes	0	None	No damage	DS0	No damage	LS1	Service
	<0.5	Low	Minor siltation	DS1	Minor damage	LS3	No service
	0.5-2.0	Low	Scouring, exposure and floatation, debris strikes, damage at bridges	DS2	Moderate damage	LS3	No service
	>2	Medium	Scouring, exposure and floatation, debris strikes, damage at bridges	DS3	Major damage	LS3	No service

Table F.7. Vulnerability matrix for landline infrastructure. Derived from Horspool & Fraser, (2016) and Williams, (2016).

	Damage Type			Damage State		Level-of-Service	
	Flow Depth (m)	**Probability of damage**	**Description**	**Metric Value**	**Description**	**Metric Value**	**Functionality State**
Buried Cables	0	None	No damage	DS0	No damage	LS1	Service
	<0.5	Low	Scour of backfill material	DS1	Minor damage, not to cable	LS1	Service
	0.5-2.0	Medium	Scoured and exposed – especially at entrance to buildings, ducting & cables across waterways damaged or severed, corrosion if cable housing compromised	DS2	Moderate damage, some cables	LS3	No service
	>2	Medium-High	Scoured and exposed – especially at entrance to buildings, ducting & cables across waterways severed, debris impacts, corrosion if cable housing compromised	DS3	Major damage	LS3	No service
Exchange centers	0	None	No damage	DS0	No damage	LS1	Service
	<0.5	Medium	Minor water damage to interiors	DS1	Minor damage		Don't know
	0.5-2.0	High	Scour of foundations, water damage to interiors, short circuiting of electrical components, washout of light structures	DS2	Moderate damage	LS3	No Service
	>2	High	Scour of foundations, water damage to interiors, short circuiting of electrical components, collapse, washout	DS3	Major damage	LS3	No Service
Switch boxes	0	None	No damage	DS0	No damage	LS1	Service
	<0.5	Medium	Water damage to internal components	DS1	Minor damage	LS3	No service
	0.5-2.0	High	Debris impacts, water damage to internal components, washout	DS2	Moderate damage	LS3	No service
	>2	High	Debris impacts, water damage to internal components, washout	DS3	Major damage	LS3	No service

Table F.8. Vulnerability matrix for airports. Derived from Horspool & Fraser (2016) and Williams (2016).

	Damage Type			Damage State		Level-of-Service	
	Flow Depth (m)	**Probability of damage**	**Description**	**Metric Value**	**Description**	**Metric Value**	**Functionality State**
Runway	0	None	No damage	DS0	No damage	LS1	Service
	<0.5	Low	Silt & light debris coverage, ponding, shorting of low lying electronic components	DS1	Minor damage, require cleanup of runway	LS3	No Service
	0.5-2.0	High	Damage to lighting, debris coverage, ponding, shorting of electronic components	DS2	Moderate damage, require substantial cleanup of runway and replacement of lights	LS3	No service
	>2	High	Damage to lighting, debris coverage, ponding, shorting of electronic components	DS3	Major damage, require substantial cleanup of runway and replacement of lights	LS3	No service
Planes	0	None	No damage	DS0	No damage	LS1	Service
	<0.5	Negligible	Negligible	DS1	Negligible damage, may require minor cleanup of sediment or debris from wheels	LS1	Service
	0.5-2.0	High	Small planes floated, debris strikes, impact damage	DS2	Moderate damage, mechanical repairs required	LS3	Service
	>2	High	Planes floated, debris strikes, impact damage, fuel tanks breached	DS3	Major damage, significant mechanical repairs or replacement of parts required	LS3	Service
Buildings	0	None	No damage	DS0	Promptly usable without repair or clean up		

	<0.5	Low	Silt infiltration, water damage to interiors	DS1	reusable after minor repairs and/or cleaning, most contents require replacement		
	0.5-2.0	High	Silt infiltration, water damage to interiors, wall washout, scour of foundations	DS2	Some structural damage, moderate sediment coverage and flooding, possibly reusable after repair and clean up. Most, if not all contents require replacement		
	>2	High	Debris strikes, water damage to interiors, structural collapse, scour of foundations, wall washout, complete washout,	DS3	Mostly irreparable structural damage, building has either collapsed, overturned, washed away or only the foundation remains.		
Machinery	0	None	No damage	DS0	No damage	LS1	Service
	<0.5	Low	Water damage to electrical components	DS1	Minor damage, electrical components require replacement	LS3	Service
	0.5-2.0	High	water damage to electrical components, debris strikes	DS2	Moderate damage, mechanical and electrical repairs or replacement required	LS3	No Service
	>2	High	water damage to electrical components, debris strikes, impact damage, washout	DS3	Major damage, replace asset	LS3	No Service

Figure F.4. Examples of airport damage states. Top Left: Sir Inia Tuuta Memorial Airport, Chatham Islands, retrieved from Air Chathams, n.d. Top Right: Malé Airpor, DS1 from the 2004 Indian Ocean tsunami, retrieved from Wikimedia Commons (2017). Bottom Right : Matsushima Airport DS2 from the 2011 GEJ Tsunami, retrieved from Taylor, 2011. Bottom Right : Sendai Airport at DS3 following impact from the 2011 GEJ tsunami, retrieved from De Vido, 2011.

Appendix G. Supporting Workshop Information

G.1. Tools and activities for HVCA

Tools and activities that have been used by NGO's to carry out HVCA include;

- *Participatory mapping*; which involves the community identifying and plotting hazardous areas (where hazards have occurred before), exposed and vulnerable assets in their community. Mapping exercises also allow participants to experiment with desired and useful risk reduction initiatives e.g. relocating assets, mapping safe areas and evacuation routes (Cadag & Gaillard, 2012; Twigg, 2004; DRR Working Group, 2012; Benson et al., 2007).
- *Community timelines*; the participants record the history of their community from their earliest memory on a timeline including events such as establishment of roads, key factories, schools, and hazard occurrences. This activity initiates conversations about shared history and may provide information on the frequency of hazard occurrence (DRR Working Group, 2012).
- *Stories and oral histories*; participants share stories and oral histories of what happened during past hazard/disasters. This may provide information on locations impacted in the past, how people were affected, and their response and recovery initatives (DRR Working Group; 2012; Twigg, 2004).
- *Community calendars*; in which participants record when cultural, economic, social or environmental events occur throughout the year. This may include holidays, busy tourist seasons, harvesting or lambing season and identify times when the community may be more vulnerable to impact from a hazard, or have more capacities (Twigg, 2004; IFRC, 2006).
- *Transect walks;* involve participants and facilitators walking through the community and gathering spatial awareness information to gain a better picture of the community. Transects can be used to locate key community service centres, schools, workplaces, social groups etc. and any potential issues resulting from new initiatives (DRR Working Group, 2012)
- *Vulnerability trees, flow charts and/or brainstorming*; involve the community identifying potential impacts a hazard may have on the community (physical, financial, cultural, social), why those impacts may occur in terms of sources of vulnerability (e.g. low income, isolation), and identifying underlying external influences that exacerbate vulnerability (e.g. legislation, climate

change). The same process can be repeated, identifying capacities to reduce impacts. This allows the community to visualise their vulnerabilities and capacities (DRR Working Group; 2012; Twigg 2004).

These tools help identify and collate hazard, exposure and vulnerability information derived by the community. Their application can be facilitated through semi-structured interviews, focus groups or workshops. Guidance on planning community workshops and facilitating these activities is provided by the DRR Working Group (2012).

Once the community has identified their hazard/s, vulnerabilities and capacities, the next crucial step is to plan how the community may reduce future disaster risk (DRR Working Group, 2012). The community/participants come together to formulate ideas on potential actions that could be taken to reduce vulnerabilities and build capacity over both short and long terms, and on who may carry out these actions (individual, households, businesses, agencies, government). Actions can then be prioritised. The DRR working group also state that monitoring and review are crucial to enable stakeholders to measure progress and track how initiatives are progressing – leading to revisions of the actions if necessary (DRR Working Group, 2012).

G.2. Workshop Survey

1. Did you find this workshop useful? (Circle one)

YES	UNSURE	NO
1a) How useful was the workshop? (Circle one) A little useful Somewhat useful Very useful ***1b) What parts of the workshop were useful? (Check all that apply)*** ☐ Information on tsunami hazard for the Chatham Islands ☐ Information on potential impacts to infrastructure ☐ The consequences activity ☐ The tsunami warning timeline activity ☐ Other ____________	***Check/circle points that apply to you from both sections***	***1c) Why wasn't this workshop useful? (Check all that apply)*** ☐ I didn't understand the information presented ☐ I didn't get a say during the activities ☐ Tsunami risk doesn't apply to me ☐ The scenario was unrealistic ☐ A tsunami won't occur on the Chathams ☐ The workshop was too late in the day ☐ Other ____________

2. Did you find any information surprising? What information or discussion topics interested you most?

____

____

3. Which industry sector/s applies to you (Circle all that apply)

Agriculture Fisheries Tourism Food and Beverage Education Healthcare Emergency Services Personnel Infrastructure personnel Other____________

4. After the workshop, how likely are you to take action to reduce tsunami risk, whether it be at individual, household or business level? (Circle one)

Won't take action Probably won't Maybe Quite likely Defiantly will

4a. What is the reason for your answer above?

____

5. How could we improve the workshop? Any suggestions?

____

____

Thank you for your feedback, it is greatly appreciated and will help resilience workshop organisers plan more useful community workshops in the future. Please return to one of the workshop facilitators or if you would like some more time you can email to kristie-lee.thomas@pg.canterbury.ac.nz or arrange to give this to us later.

Figure G.1. Workshop Survey.

Table G.1. Data collected from survey respondents.

Survey Respondent	Q1 Did you find the workshop useful?	Q1a How useful was the workshop?	Q1b What parts of the workshop were useful? - Info on tsunami hazard	Q1b What parts of the workshop were useful? - Info on potential impacts to infrastructure	Q1b What parts of the workshop were useful? - The consequences activity	Q1b What parts of the workshop were useful? - The tsunami warning timeline activity	Q1b What parts of the workshop were useful? - Other	Q1c Why wasn't this workshop useful?	Q2 Did you find any information surprising…	Q3 What industry sector applies to you?	Q4 After the workshop how likely are you to take action…	Q4a: What is the reason for your answer above?	Q5: How could we improve the workshop? Any suggestions?
1	Yes	Very Useful	1	1	No Data	No Data	No Data	No Data	Mapping and historical tsunami information	Emergency services	Definitely will	Part of my occupation	Information was very well delivered, very impressed
2	Yes	Very Useful	1	1	1	1	looking at the maps, showing the areas that might be affecting and services etc.	No Data	No but it was good looking back in time, the number of times it has happened and what areas were really affected	Emergency services	Definitely will	Keeping whānau informed and advising what to do in that situation	Having the workshop in the evening or later that day
3	Yes	Somewhat Useful	1	1	1	1	No Data	No Data	No Data	Fisheries	Quite likely	No Data	No Data
4	Yes	Very Useful	1	1	1	1	No Data	No Data	No Data	Infrastructure personnel	Quite likely	Give my staff a better understanding of the risks	No Data
5	Yes	Very Useful	1	1	1	1	How prepared we are as individuals	No Data	Not surprising but interesting topic: good respected managers, communication outlets, time to act hours vs short 45 min	Retired - Agriculture but ex emergency services	Definitely will	Live at lake level, need time to get all useful stores to high ground	Keep asking - are you aware? - safeguard your family, no loss of life
6	Yes	No Data	1	1	1	1	No Data	No Data	Not surprising but interesting topics: all of the above, every bit of information is helpful	Fisheries and emergency service personnel	Definitely will	Part of my occupation	I thought it went very well

G.3. Living Costs on the Chatham Islands

While there is no available data on the repair or recovery costs of a high-impact tsunami on the Chatham Islands, Table B-1 provides an overview of the cost of living in the Chatham Islands compared to New Zealand.

Table G.2. Comparison of Chatham Islands and mainland New Zealand household/living costs. Retrieved from Leung-Wai & Borren (2017, p.21).

Household cost	Unit(s) measured	Period	Chatham Islands	NZ average	CI : NZ ratio
Energy and fuel					
Electricity	Cost per kWh (GST excl.)	July 2017	$0.58	$0.29	**2.0**
Petrol	Cost per litre (GST incl.)	July 2017	$2.85	$1.80	**1.58**
Diesel	Cost per litre (GST incl.)	July 2017	$1.40	$1.12	**1.25**
Telecommunications					
Internet, phone line and national calling	Cost per month for ADSL Internet, 80GB of data, landline rental, and national calling package (GST incl.)	July 2017	$217.35	$100.00[16]	**2.17**
Housing					
Rent	Median weekly rent paid by households	As at March 2013	$110.00	$280.00	**0.39**
Rates	Average annual rates paid by households	YE June 2013	$2,096.00	$2,165.78[17]	**0.97**
Food and household goods					
Fruit and vegetables	Retail price of selected items in FPI and CPI (GST incl.)	Sep Q, 2014	N/A	N/A	**2.62**
Meat, Poultry, and fish			N/A	N/A	**1.36**
Grocery food			N/A	N/A	**2.55**
Non-alcoholic beverages			N/A	N/A	**2.11**
Household goods			N/A	N/A	**1.73**
Total food and household goods			N/A	N/A	**2.20**

Sources: Electricity prices: Chatham Islands Enterprise Trust (Chatham Islands); MBIE (New Zealand). Telecommunications prices: Farmside 80GB plan (Chatham Islands), Spark, Vodafone, rural wireless broadband 120GB plan). Petrol and diesel prices: Waitangi Hardware, Dough n Go (Chatham Islands); Statistics New Zealand Consumer Price Index, (New Zealand). Rent: Statistics New Zealand 2013 Census (Chatham Islands and New Zealand). Rates: NZ Taxpayers Union (Chatham Islands and New Zealand). Food and household goods: Waitangi Store, Dough n Go (Chatham Islands); Statistics New Zealand Food Price Index and Consumer Price Index (New Zealand).